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ANALYSIS OF THE RESPONSE OF HEALTHY AND DECLINING SUGAR MAPLE TREES TO FERTILIZATION

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Executive Summary

A fertilizer trial program was initiated in 1988 by the Ontario Ministry of the Environment at the Environmental Phytotoxicology Section to assess the usefulness of inorganic fertiliser amendments to combat decline of sugar maples in Ontario.

Two stands were selected on the Canadian Shield in the Muskoka region and two in the Peterborough area on calcareous soils. One stand in each area was tapped for the purpose of maple syrup production and the other was not. Healthy and declining trees in each stand were assessed for canopy decline using a numerical index of tree stress symptoms. Three healthy and three declining trees in each stand were fertilized in early November 1988 with one of the following seven fertilizer amendments: nitrogen, phosphorous, potassium, calcium, magnesium lime and combined nutrient addition. Healthy and declining trees were also selected at each stand to be controls, and were not fertilized. Trees were assessed for decline prior to fertilization in 1988 and subsequent to fertilization in 1989 and 1990. Foliage and soil samples were also collected before (1988) and after fertilizer treatment (1989) and analyzed for a variety of chemical parameters. A variety of statistical techniques were used to assess overall responses in decline index to fertilizer amendments for both location and decline specific responses. The relationships between soil and tree chemistry and decline status were also analyzed.

There was a general tendency toward reduced canopy health from 1988 to 1989 for both treated and control trees. In the Peterborough this trend continued through 1990 for untreated controls. However, from 1989 to 1990 control trees in Muskoka tended to improve in condition with this improvement being statistically significant for declining trees in the tapped stand and healthy trees in the untapped stand.

When considering all plots and decline categories, fertilizer amendment had an overall positive impact on canopy condition with the total (combined) nutrient formula resulting in the greatest and only statistically significant improvement. While mean regional responses to fertilizer application were consistently positive in Peterborough they were negative in Muskoka. Declining trees showed greater response to fertilizer than healthy trees, but not consistently for all stands. Fertilizer treatment produced different responses at different sites even among declining and healthy categories indicating that the response is a site specific phenomena.

Analyses relating the soil and foliar chemical status of sample trees to fertilizer response indicated that while some fertilizer responses were consistent with those exacted based on baseline soil and foliar chemistry many were not. Similarly, prefertilization foliar and soil chemistry were in some cases related to decline index and in other cases not related. Where stronger relationships did occur, fertilizer responses were not always intuitive.

Table of Contents

1.0 Introduction 1

2.0 Methodology 3
  2.1 Experimental Design 3
    2.1.1 Plot Establishment, Tree Selection and Tree Assessments . . . 3
    2.1.2 Fertilization 3
  2.2 The Decline Index (DI) 6
  2.3 Field Sampling 8
  2.4 Chemical Analyses 8
  2.5 Statistical Methods 9
    2.5.1 Analysis of Variance on Tree Decline 9
    2.5.2 Relating Soil and Tree Chemistry and Decline Status 11
  2.6 Database Management Techniques 13

3.0 Results and Discussion 15
  3.1 Analysis of Variance on Tree Decline 15
    3.1.1 General Trends in Decline Index 15
    3.1.2 Planned Comparisons 18
    3.1.3 Tests on Effects Suggested By the Data 21
    3.1.4 Decline Index Components 26
  3.2 Soil and Tree Chemistry and Decline 28
    3.2.1 General Examination of Baseline Soil and Tree Chemistry 28
    3.2.2 T-Test on Healthy and Declining Foliar and Soil chemistry 32
    3.2.3 Scatter Plot Matrices 33
    3.2.4 Canonical Correlation 38
    3.2.5 Analysis of Covariance 42
    3.2.6 Analysis of Variance on Soil and Foliar Chemistry 45

4.0 References 48

Appendix A Soil and Foliar Chemistry 50

A variety of codes are used in the report to represent the design variables. They are listed below:

L = LOCATION (M = MUSKOKA = 1, P = PETERBOROUGH = 2)
D = DECLINE STATUS(DECLINING = D = 1, H = HEALTHY = H = 2)
T = TAPPING STATUS(TAPPED = T = 2, UNTAPPED U = 1)
F = FERTILIZER(C = CONTROL = 1, CA = CALCIUM = 2, K = POTASSIUM = 3, L = LIME = 4, MG = MAGNESIUM = 5, N = NITROGEN = 6, P = POTASSIUM = 7, T = TREATMENT = 8(ALL))

DI	MEAN DECLINE INDEX

Soil Chemistry Parameters

ALESC	Soil aluminum (millequiv/100g)
ALECA	Dry weight as Al (μg/g)
CAESC	Soil calcium (millequiv/100g)
SNITRO	Soil nitrogen total (mg/g dry weight as N)
SPPUT	Soil total phosphorous (mg/g dry weight as P)
KKESC	Soil potassium exchangeable (millequiv/100g)
MGESC	Soil magnesium exchangeable (millequiv/100g)
ORGC	Soil organic carbon
PHECA	Soil pH measured w $CaCl_2$
PHEW	Soil pH in water (dimensionless)
PPO4BE	Soil phosphorous (mg/g dry weight as P)
SSO4EW	Soil sulphate (μg/g dry weight as SO_4)
TIC	Soil total inorganic carbon (% dry weight as C)

Foliar Chemistry

ZNUT	Foliar zinc (μg/g dry weight as Zinc)
SSUT	Foliar sulphur (μg/g dry weight as sulphur)
MNUT*	Foliar manganese (μg/g dry weight as manganese)
MOUT*	Foliar molybdenum (μg/g dry weight as molybdenum)
NAUT	Foliar sodium (μg/g dry weight as sodium)
NIUT*	Foliar nickel (μg/g dry weight as nickel)
NNTKUR	Foliar nitrogen (mg/g as nitrogen)
PBUT	Foliar lead (μg/g)
PPUT	Foliar potassium (μg/g dry weight as potassium)
ALUT*	Foliar aluminum (μg/g dry weight as aluminum)
BBUT*	Foliar boron (μg/g dry weight as boron)
CAUT*	Foliar calcium (μg/g dry weight as calcium)
CDUT*	Foliar cadmium (μg/g)
CLUT	Foliar chlorine (μg/g dry weight dry wt. as chlorine)
CUUT*	Foliar copper (μg/g dry weight as copper)
FEUT*	Foliar iron (μg/g dry weight as iron)
KKUT	Foliar potassium (μg/g dry weight as potassium)
MGUT*	Foliar magnesium (μg/g dry weight as magnesium)

Key to codes used in the report

1.0 Introduction

Forest declines, although not new phenomena, have been reported widely in the last decade. Accelerated declines in both deciduous and coniferous forest stands have been documented in both Europe and North America. While declines of individual species in some areas have shown signs of recovery in the last few years [eg. Norway spruce and Silver fir in West Germany (Blank et al., 1988; Ulrich, 1988)], many declines continue at seemingly unprecedented rates.

Hardwood declines were first reported in North America around 1913 in the northeastern United States (Hartly and Merrill, 1915). Historical declines occurring in Ontario, Quebec and the northeastern United States involved a number of species including sugar maple, ash and both yellow and white birch (Auclair, 1987). Surveys in Ontario and Quebec have tended to concentrate on sugar maple decline because of the seriousness of the decline and because of sugar maple's economic importance.

The most recent forest decline in eastern Canada was first observed in 1978 in Quebec forests by sugar maple producers. In Ontario, severe sugar maple declines occurred in the Parry Sound and Owen Sound districts during the period of 1977 to 1979 (Canadian Forestry Service, 1980). In 1984 maple syrup producers from the Muskoka area alerted the Ontario Ministries of Agriculture (OMAF) and Environment (MOE) to accelerated declines in their woodlots. A number of programs were subsequently initiated by the MOE to address critical aspects of the decline. These programs included:

1) **The Ontario Hardwood Decline Survey (1985 - present):**
   Investigating regional and temporal trends in canopy decline across the province

2) **The Dendrochronology of Hardwood Species in Ontario Study (1985,1989):**
   Examining regional and temporal trends in hardwood tree growth across the province and in relation to zones of air pollution deposition

3) **The MOE Maple Decline Study (1984 - present):**
   Assessing the extent and cause of sugar maple decline in Muskoka, Peterborough and Thunder Bay

Historically the causes of many documented declines remain unclear. While convincing cases have been made for single or multiple-factor causes of specific declines, the complexities of most forest declines makes certainty an impossibility. Although some declines may be attributed to poor management practices, many areas in the province show decline in the absence of human intervention.

A number of forest decline studies in Europe and North America have identified nutrient disorders in the soil and foliage of trees in declining stands (Zoettl, 1987; Bernier and Brazeau, 1988a,b,c; Tomlinson, 1987). Fertilizer trials have been initiated in a number of these studies to help identify nutrient disorders in declining stands and to determine whether fertilizers can ameliorate accelerated declines (eg. Hendershot and Jones, 1989). Recent fertilizer trials in Quebec suggest that applications of magnesium, calcium and potassium to declining sugar maple stands may ameliorate foliar nutrient deficiencies and canopy decline symptoms.

The primary purpose of this study was to identify practical and timely solutions to hardwood decline problems in Ontario woodlots. Specifically, the study was designed to:

1) Identify soil and foliar elements critical to healthy growth of sugar maple in the province.

2) Investigate specific responses of declining trees to a variety of nutrient applications.

3) Identify specific responses of stands in Muskoka and Peterborough to nutrient amendments.

4) Investigate relationships between foliar and soil chemistry and canopy health.

2.0 Methodology

2.1 Experimental Design

2.1.1 Plot Establishment, Tree Selection and Tree Assessments

Four (4) sugar maple stands were selected in Ontario during the summer of 1988. Figure 2.1 illustrates the location of the four stands as well as the location of the hardwood decline survey plots. Two stands were established in the Muskoka region on podzolic soils overlying late to middle precambrian rock. Two additional stands were established in the Peterborough area on brunisolic soils overlying calcareous substrate. Table 2.1 contains a brief summary of soil properties within each of the stands. One stand in each of the two areas was managed for maple syrup production and one was not. Trees within these stands were dominantly sugar maple and not severely affected by forest tent caterpillar or other major defoliators at the time of selection. Stands were also chosen to be similar in slope, tree density, size class distribution and species composition where possible.

Twenty-four (24) healthy and twenty-four (24) declining trees were selected within each plot. Trees were chosen to be codominant and to not have interlocking drip lines. All trees were rated for canopy decline by two independent observers using the MOE numerical rating system (see Section 2.2). Trees were assessed for decline prior to fertilization in 1988 and subsequent to fertilization in 1989 and 1990. Assessments were made during mid to late summer in each assessment year.

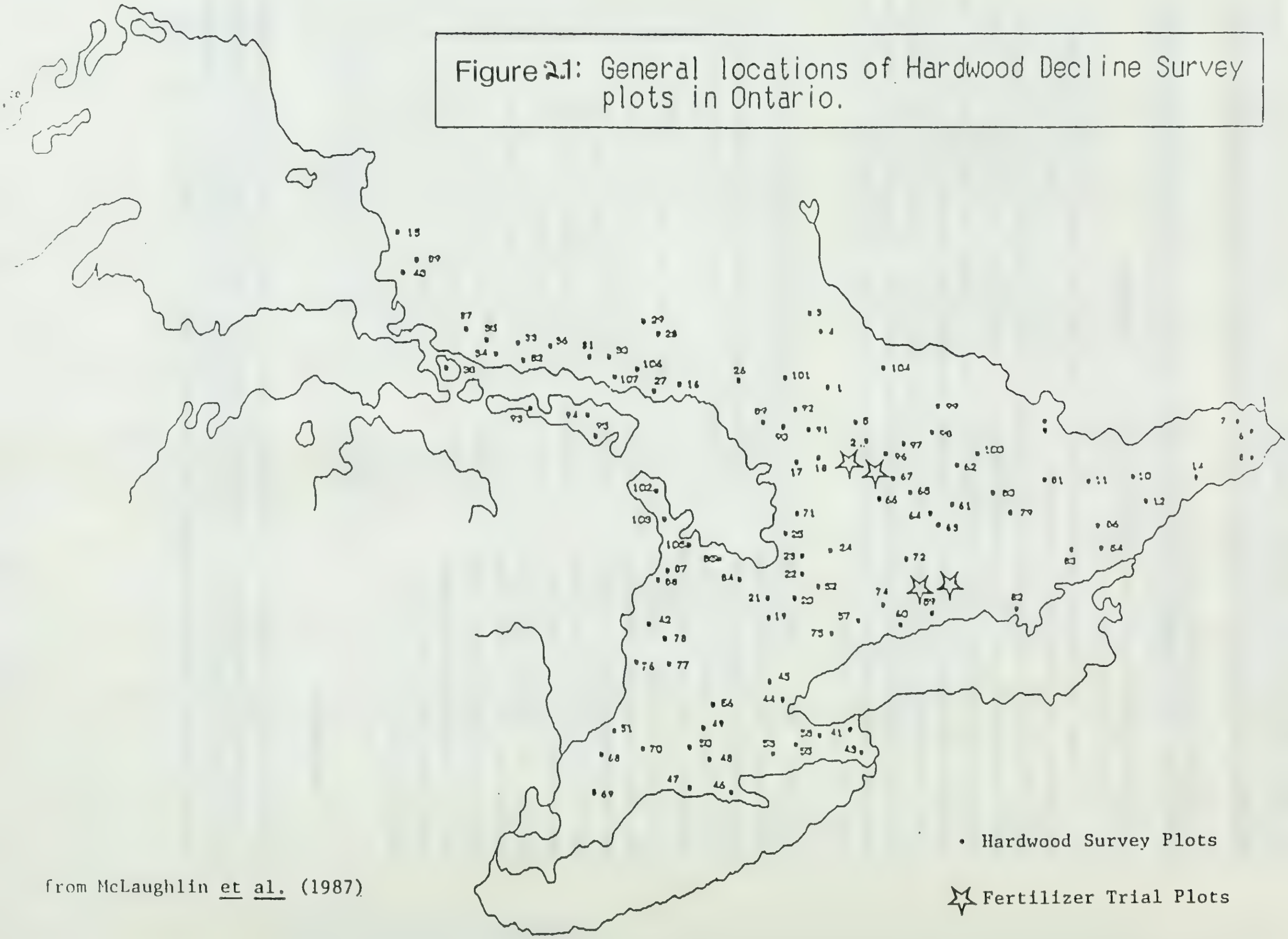
Table 2.2 Fertilizer treatments and application rates

NUTRIENT	FORM	APPLICATION RATE (kg/ha)
1. Control		
2. Nitrogen	Sulphur coated urea	100
3. Phosphorous	Triple super phosphate	100
4. Potassium	Sulphur-coated potassium sulphate	100
5. Calcium	Calcium sulphate	100
6. Magnesium	Magnesium sulphate	100
7. Line	Dolomitic lime	2,000
8. Total (combined)	Nutrients 2 to 6	500

2.1.2 Fertilization

Eight (8) fertilizer treatments were used at each of the study stands. The treatments were control (C), nitrogen (N), phosphorus (P), calcium (Ca), potassium (K), magnesium (Mg), dolomitic lime (L) and full nutrient (Total) (ie. a combination of N, P, K, Ca and Mg). The rates and chemical forms of the nutrients applied are outlined in Table 2.2. All fertilizers were applied

Figure 2.1: General locations of Hardwood Decline Survey plots in Ontario.



from McLaughlin _et_ _al._ (1987)

Table 2.1 Soil characteristics

PLOT	HORIZON	COLOUR	TEXTURE	STRUCTURE	HORIZON	STONINESS	DEPTH
Peterborough Breckonridge	Ahe	10YR 2/1	Loam	Granular	Gradual/Wavy	None	0 - 20
	Bm1	7.5YR 3/4	Sandy loam	Weak medium subangular blocky	Gradual/smooth	None	20 - 35
	Bm2	7.5YR 3/4	Sandy loam	Weak medium subangular blocky	Gradual/smooth	None	35 - 45
	Ck	10YR 6/3	Loamy sand	Single grain		None	45 +
Peterborough Davies	Ah	10YR 2/2	Silt loam	granular	clear/wavy	None	0 - 20
	Bm1	10YR 4/3	Silty clay loam		gradual wavy		20 - 45
	Bm2	10YR 3/4	Silty clay loam		clear/irregular		45 - 70
	Ck1	10YR 4/4	Silty clay loam			Very stony	70 - 85
	Ck2					Very stony	85 +
Muskoka Leslie Frost Centre	LFH				Clear/smooth		4 - 0
	Ahe	10YR 3/1	Sandy loam	Weak fine subangular blocky	Gradual/broken	Very	0 - 10
	Bf	5YR 3/1	Sandy loam	Weak medium subangular blocky	Gradual/wavy	Moderate	10 - 25
	BC	10YR 4/6	Sandy loam	Weak medium subangular blocky	Diffuse/irregular	Very	25 - 45
	C	10YR 5/6	Loamy sand	Single grain		Very	45 +
Muskoka Boothby	LFH				Clear/smooth	Very	4 - 0
	Ah	10YR 3/4	Loam	Weak fine subangular blocky	Gradual/wavy	Very	0 - 5
	Bhf	7.5YR 3/4	Sandy loam	Weak fine subangular blocky	Abrupt(rock)	Very	5 - 35
	Bedrock	35 +					

at a rate of 100 kg of the test element per hectare except the full nutrient and lime amendments. The full nutrient treatment was a blend of equal weights of elemental N, P, K, Ca and Mg and applied at a rate of 500 kg/ha. Lime was applied at a rate of 2000kg/ha. Treatments were applied in 1988 on a per tree basis and the amount of fertilizer applied was pro-rated based on the above per hectare application rates. The area fertilized around each test tree was calculated as the fine root absorption area, a function of the diameter at breast height (Lamson, 1987), assuming that this area surrounding the tree is approximately equal to the calculated crown diameter.

Three healthy (3) and three declining trees were selected for each of the eight (8) treatments at each of the study stands. Trees in each decline category were stratified by diameter into three groups. Test trees within each of the stratified groups (replicate groups) were assigned randomly to one of each of the eight treatments. Trees were stratified by diameter to insure that individual treatments were not entirely compromised of extremes in diameter class. Fertilizers were applied in the fall of 1988 within the dripline of the crown using a shoulder carried cyclone spreader.

2.2 The Decline Index (DI)

The symptoms of stress which most commonly accompany hardwood decline in Ontario are:

- Branch dieback - including progressive dieback of both fine and larger branches.
- Foliar chlorosis - yellowing of varying degrees as the result of loss of chlorophyll pigments.
- Undersized leaves.

A number of other related symptoms include delayed spring bud flush, early leaf fall colour, premature leaf abscision, epicormic sprouting, reductions in annual xylem increment and increased root mortality. Of all visible symptoms commonly associated with sugar maple decline in Ontario twig/branch dieback and foliar colour and size were the most frequently cited on declining trees in a survey of more than 650 members of the Ontario Maple Syrup Producers Association (McLaughlin and Butler, 1987). The Phytotoxicology Section of the MOE has used these characteristic symptoms of decline to develop a composite index of canopy decline (McLaughlin et al., 1989). The three descriptive crown parameters are combined into a weighted formula which yields a numeric DI value ranging from 0 (healthy tree, no symptoms) to 100 (dead tree).

The DI formula is:

$$DI = DB + (A * UL) + (A * ST) + (A * SL/2)$$

where DI = decline index
DB = % dead branches
UL = % undersized leaves
ST = % strong chlorosis
SL = % slight chlorosis
A = a weighting factor (100-DB/400)

The weighting factor relates the foliar characteristics proportional to the live crown.

Therefore, a tree which has an abundance of small and/or chlorotic leaves but relatively little twig/branch dieback will have an elevated DI. The decline index therefore provides a means for quantifying the severe effects of chronic stress as well as less severe and potentially diagnostic early warning signs of more subtle or short term stress.

The reproducibility of the DI has been tested in field trials in Ontario (McLaughlin et al., 1989). The results of the trials indicate that the method is clearly reproducible and that confidence intervals are acceptably narrow for crews within a given season. The coefficient of variation was inversely related to decline index. This may simply indicate that the inherent variability in the DI is independent of the health status of the tree, but simply has a proportionally greater impact on trees with lower decline ratings. The results may also indicate however that healthier trees are more difficult to accurately assess. This may be a reflection of the difficulty in assessing the more subtle symptoms of decline (eg. foliar chlorosis and leaf size) and/or difficulty in accurately assessing the severity of decline symptoms when a small percentage of the canopy is impacted.

Seasonal variability in decline assessment is difficult to assess. Testing of the same crews during different seasons would be difficult to interpret because the trees used for assessment trials will not be identical between seasons. Testing the variability between crews and during different seasons is even more difficult. Therefore, a consistent training and testing program has been adopted to try to minimize crew to crew and season to season variability in decline assessments.

This study represents the first use of this decline index to assess responses of sugar maple trees to fertilization.

2.3 Field Sampling

Foliage and soils samples were collected both before and after fertilization. Foliage samples were collected using a shotgun during late July in 1988 prior to fertilization and in 1989 and 1990 subsequent to fertilization.

Foliage samples were collected in triplicate from sun exposed areas in the mid-crown of each sample tree. It was essential to conduct sampling of foliage prior to foliar senescence and associated nutrient effluxes (Bartuska, 1984). Although concentrations of foliar nutrients in the lower crown are thought to be the least variable of all positions in the crown (Morrison, 1984), declining trees often show symptoms higher in the crown.

Soil samples were obtained in triplicate from within the dripline of each sample tree in mid-September of 1988, 1989 and 1990. Samples were collected using a 2.5 cm diameter stainless steel soil corer from 0-15 cm below the L and F layers. A minimum of ten cores were collected for each of the triplicate samples. Soils were transported to the laboratory in plastic sample bags, air dried, disaggregated and passed through a 2mm stainless steel sieve. Subsamples of this sieved fraction were ground to pass through a 45 mesh sieve for bulk chemical analysis. The 2mm fraction was processed for pH, conductivity and particle size measurements as well as extractable concentrations of soil elements.

2.4 Chemical Analyses

Foliar samples were dried, ground and analyzed for the substances shown in the "key to codes" table at the beginning of the report. Those elements listed which are marked with a "*" were analyzed by ICP-AES (Automated Inductively Coupled Plasma Optical Emission Spectrometer) after hot digestion in a nitric/sulphuric acid mixture. Sodium was also analyzed after hot acid digestion using an AA (Atomic Absorption Spectrophotometer). Samples for chlorine, sulphur and potassium analysis were imbedded in wax and analyzed by X-ray fluorescence. Sulphur and phosphorus were analyzed by colourmetry. The specific details of foliar analytical techniques are available through the Laboratory Services Branch of the MOE.

Soils collected from sample trees were also analyzed for the substances shown in the "key to codes" table shown at the beginning of the report. All soil chemical analyses were conducted by the MOE Laboratory Services Branch using standard APIOS (Acidic Precipitation in Ontario Study) protocol (MOE, 1986). Soil acidity was determined for all soils in both distilled water and 0.01 M calcium chloride. Exchangeable cations, including Ca, K, Mg and Al, were measured at the pH level of the soil using 2N sodium chloride. Readily soluble aluminum was determined by extraction with 0.01 M calcium chloride. This fraction of aluminum strongly correlates with aluminum uptake by plants and its adverse effects on crop yield. Nitrogen and phosphorus are converted to simple organic forms for total analysis by dissolution of the samples in hot concentrated sulphuric acid and potassium persulphate and analyzed by colourimetry. Extractable phosphorus was determined by the Bray method which involves an ammonium flouride/HCl extraction. Water-soluble, plant-available sulphate was extracted using distilled water. Total inorganic carbon was measured by automated coulometric titration after reaction with 2N HCl in a closed system. Organic carbon was reported as the difference between total carbon, as measured by a LECO carbon analyzer, and total inorganic carbon.

2.5 Statistical Methods

The majority of statistical tests and graphics were completed using the SYSTAT 5.0 statistical package. For convenience, the T-test for foliar and soil chemistry was coded in the database language.

Table 2.3 ANOVA design

SOURCE	DEGREES OF FREEDOM
LOCATION (L)	1
TAPPING(T)	1
L x T	1
HEALTHY VS DECLINING (D)	1
FERTILIZER (F)	7
D x F	7
D x L	1
F x L	7
D x F x L	7
D x T	1
F X T	7
D x F x T	7
D x L x T	1
F x L x T	7
D x F x L x T	7
TOTAL	191

2.5.1 Analysis of Variance on Tree Decline

The analysis of variance appropriate for the design used in the study is shown in Table 2.3. The response variable used for the analysis was the change in decline index from 1988 to 1989 and from 1988 to 1990. For example the ANOVA was performed on the decline index for 1988(DI_{88}) minus DI_{90}. This was done for the composite decline index and the individual parameters used to calculate the decline index for 1988 - 1989 and 1988 - 1990.

2.5.1.1 Planned Comparisons

Multiple means tests also called multiple comparison procedures are often used in discerning differences between factor means in an analysis of variance. A disadvantage of using these tests is the effectiveness of such tests in discerning differences between means. Because the maximum number of comparisons between means are made, each with a probability of falsely rejecting the null hypothesis, the level at which two means are considered to differ is set conservatively to account for this cumulative probability. Many of these comparisons may not be of interest to the investigator.

When a finite number of comparisons are identified prior to examining the data, these single degree of freedom "planned comparisons" can be tested at a fixed probability level with considerably more power (of rejecting the null hypothesis that two means are equal) than multiple means tests.

A number of planned comparisons were identified prior to analysis of this data base with specific consideration given to the experimental design, the objectives of the study and expected responses of healthy and declining trees in Muskoka and Peterborough to fertilization. The planned comparisons for canopy condition included:

Overall responses in DI of

- individual fertilizers relative to the control
- the total nutrient amendment relative to individual fertilizer treatments
- lime compared with response to individual elemental components of lime

Location specific responses (Muskoka vs. Peterborough) in DI

- between controls
- across all treatments
- to individual treatments

Decline specific responses (Declining vs. Healthy) in DI

- between controls
- across all treatments
- to individual treatments
- in different locations

2.5.1.2 Tests on Effects Suggested By the Data

Following a full consideration of all planned comparisons a systematic approach was taken to investigate other significant responses which may have occurred in the study. The general method used to determine appropriate tests suggested by the data was to first run the ANOVA and then use the significant terms in the ANOVA to direct contrasts. Control corrected response is defined as:

Control corrected response = Treatment mean - Control mean

Tables of appropriate control corrected responses were produced to drive the analysis. For example, if L*D proved to be significant in the ANOVA then a L by D table of control corrected responses was produced and distinctly different means would be contrasted.

2.5.1.3 Components of the Decline Index

ANOVA's were performed on the four components of the decline index (DI). The P-values and mean square errors for these ANOVA's were listed. The equation for DI is shown in section 2.2.

2.5.2 Relating Soil and Tree Chemistry and Decline Status

A variety of techniques were used to establish the relationship between foliar and soil chemistry and between tree decline and these chemical variables. The methods are discussed below:

2.5.2.1 Scatter Plot Matrices

A variety of scatterplots were used to allow visual determination of the interrelationship between decline index and soil and tree chemistry. Scatterplot matrices were produced for the majority of soil and tree chemistry parameters and decline index.

2.5.2.2 Canonical Correlation Analysis

Canonical correlation analysis was used as a statistical screening technique to examine general relationships between foliar (including both canopy condition and foliar chemistry) and soil related variables. Canonical analysis allows simultaneous consideration of both criteria (foliage) and predictor (soil) data sets. While not ignoring relationships between variables within either of the data sets, the analysis extracts information about the correlation between the data sets. The technique is the multivariate equivalent of multiple correlation, in which correlations between linear combinations of a number of criteria variables, rather than a single criteria variable, and linear functions of a number of predictor variables are maximized. The analysis has the advantage of being relatively insensitive to correlations between variables within either the predictor or criteria data sets. The linear combinations of variables in each set are called canonical variates and the correlations between canonical variates are the canonical correlations. Each consecutive set of variates is orthogonal to the previous sets and has the next highest correlation. These sets of variates may describe distinctly different but important relationships between soil and foliar variables. Usually most of the covariation between the two data sets is concentrated in the first two or three canonical correlations. The first canonical correlation is at least as large as the multiple correlation between any individual criteria variable and the set of predictor variables. An F test is used to test the probability that a canonical correlation, and all smaller correlations, are zero.

The relationship between individual variables in the criteria variable set which are highly correlated with the corresponding predictor set variate are further investigated by considering the weightings of predictor set variables on their own variates. In this way for each significant set of variates a relationship between important criteria variables and important predictor variables is described.

2.5.2.3 Analysis of Covariance

There is a need to establish a baseline relationship between soil and foliar chemistry and tree decline. We must also try to understand the relationship between decline index and soil and foliar chemistry based on the categorical variables of the experimental design (ie. site, tapping and decline status and the interactions between these variables). This can be achieved through an analysis of covariance where decline index is regressed as a function of soil chemistry parameters and location, tapping and decline status and all possible interactions of these categorical interactions. The 1988 (pre-fertilization) soil chemistry was used to establish these baseline relationships. A simplified example follows:

Assuming N and P are two soil chemistry parameters the model would be:

$$DI = \text{Constant} + P + N + L + T + D + L{*}T + L{*}D + L{*}T{*}D + T{*}D + P{*}L + N{*}L + T{*}P + T{*}N + D{*}P + D{*}N + L{*}T{*}P + L{*}T{*}N + T{*}D{*}P + T{*}D{*}N + L{*}T{*}D{*}P + L{*}T{*}D{*}N$$

Location, tapping and decline (L, T and D) are treated as categorical variables with values of 0 and 1(i.e. 0 = Muskoka and 1 = Peterborough)

The ANCOVA essentially compares the slopes of the regression lines based on the factor interactions. For example the soil chemistry by location interaction produces two slopes (ie. Muskoka and Peterborough) for the relationship between chemical parameter N and decline index. Examination of the F statistic for this relationship will indicate whether the slopes are statistically different. If they are different we can conclude that the chemical variable N produces different effects on crown condition depending on the location.

At the beginning of the ANCOVA there are a very large number of interaction terms. To reduce the number of interaction terms all interaction terms with a p-value of greater than 0.15 were eliminated. If an interaction term proved to be significant at some level all lower level interaction contained in that interaction were kept in the model. For example if aluminum proved significant at the L, T, D level L*D and L*T were kept in the model. After all non-significant parameters and interactions were eliminated the model was re-parameterized to obtain the regression coefficients. In the particular case of the ANCOVA the SAS General Linear Models Procedure was used.

In the case of the soil chemistry, decline index was considered as a function of ALESC, CAESC, KKESC, MGESC, PHEW, NNTKUR, ORGC, PPO4BE PPUT SSO4EW, L, T and D and all possible interactions of these parameters in the initial model. In the case of the tree chemistry, decline index was considered as a function of ALUT, BBUT, CAUT, MGUT, PPUT, MOUT, NNTKUR, MNUT, L, T, D and all possible interactions of these parameters in the initial model. Any parameters left out were due to missing data(e.g. KKUT) , excessive correlation (e.g. PHEW and PHECA) or non-linearities (e.g. TIC).

2.5.2.4 Assessing Chemical Responses to Fertilization

A very simple check on response to fertilizer treatment is to investigate if there is a significant soil and foliar chemistry response to the chemical(s) in the treatment. For example, is there an increase in magnesium in soil and/or foliage chemistry due to magnesium treatment. To this end, analyses of variance were conducted on the difference between the 1988 and 1989 concentrations of selected soil and foliar chemistry parameters. The model was the same as the one discussed in the ANOVA for the decline index section. Planned comparisons were then conducted between the soil and foliar chemistry response in the appropriate treatment category and the control. As well the overall combined treatment was compared to the control.

2.5.2.5 T-Test on Healthy and Declining Foliar and Soil chemistry

It is of interest to examine the difference between the soil and foliar chemistry for healthy and declining trees. The 1988 soil and foliar chemistry data represents a baseline 'before fertilization' sample of chemistry. A T test for two independent samples was applied to the means for soil and foliar chemistry for declining and healthy trees to test the hypothesis that the mean value for healthy trees and declining trees are the same. For example:

$$\mu_{hAl}-\mu_{dAl}=0$$

A table of p-values was developed for each site(L*T) for the foliar and soil chemistry. As well the sign (+ or -) of the t-statistic was included to indicate the direction of the relationship between the chemistry and the decline status. For example, if the p-value were 0.05 for the test shown in the above equation, that would indicate that aluminum concentrations were significantly higher in declining trees.

2.6 Database Management Techniques

The maple decline data were placed into a normalized database design and managed using R:Base Version 3.1. At the end of the project the data were given to the client in dBase III+ format.

The database was examined for outliers. In the case of soil and tree chemistry all non-possible values were eliminated from the data after examination for obvious errors. As was indicated in the ANOVA section the ANOVA was performed on the difference between the 1988 and 1990 decline indices. Examination of this difference in the decline index and the parameters it was calculated from presented a problem. In some cases the three readings for a treatment at a site tended to be dominated by a large decrease in the decline index for one of the three readings (see table 2.4). This decrease was traced back to a large (>20 percent) decrease in the number of dead branches over the two year period. Since dead branches strongly influence the calculation of decline index (see section 2.2) a excessive (i.e. unrealistic) decrease in the number of dead branches can unduly skew the calculation.

LOCATION	TREATMENT	TREENUM	TEST	1988 RESULT	1989 RESULT	1990 RESULT	DIFFERENCES 1988-1989	1988-1990
MTD	N	2.	DB	27.9	10.0	5.3	17.9	22.6
MTD	N	2.	DI	27.8	10.0	5.4	17.8	22.4
PUD	K	4.	DB	34.5	10.0	5.0	24.5	29.5
PUD	K	4.	DI	36.3	14.5	6.2	21.8	30.2
MUD	C	6.2	DB	32.0	10.0	3.7	22.0	28.3
MUD	C	6.2	DI	35.3	13.4	4.3	21.9	31.0
MUD	P	6.5	DB	33.2	20.0	5.3	13.2	27.8
MUD	P	6.5	DI	26.3	26.0	6.4	0.34	20.0
MUD	N	12.	DB	32.5	30.	10.0	2.5	22.5
MUD	N	12.	DI	30.2	30.9	10.4	-0.66	19.8
MTD	K	16.	DB	37.2	20.0	10.0	17.2	27.2
MTD	K	16.	DI	33.8	21.0	11.2	12.8	22.6
MTD	CA	22.	DB	46.4	30.0	21.7	16.4	24.7
MTD	CA	22.	DI	44.8	30.9	22.7	14.0	22.2
PTD	CA	32.	DB	46.5	60.0	23.3	-13.5	23.2
PTD	CA	32.	DI	60.9	63.5	25.0	-2.6	35.9

Table 2.4 Dead branch outliers

It is unlikely that a tree can grow enough new branches in 2 years to decrease the number of dead branches in excess of 20 percent. Perhaps the dead branches fell off the tree or perhaps defoliated branches were originally interpreted as dead branches. It was hence decided to remove any tree that had an decrease in dead branches in excess of 20 percent. Results from eight trees were eliminated from 192 in the study.

3.0 Results and Discussion

3.1 Analysis of Variance on Tree Decline

3.1.1 General Trends in Decline Index

Previous examination of the data suggested that there was a general tendency toward reduced canopy health from 1988 to 1989 regardless of fertilization (MOE, unpubl.). Table 3.1 summarizes the general trends in the canopy condition of untreated trees and shows the results of a paired t-test, in each of the stands and for healthy and declining trees, for 1988, 1989 and 1990.

Since 1989 there has been a general improvement in the controls in Muskoka. There has been however a general (although not significant) deterioration in canopy health during the same period in Peterborough (with the exception of healthy trees in the tapped stand). There was a general although not significant decline at both sites from 1988 to 1989 with the improvement in the controls occurring between 1989 and 1990.

This baseline improvement in Muskoka is encouraging and is consistent with the results of the Hardwood Decline Survey which have documented a gradual but consistent improvement in the Muskoka area (see Figure 3.1). This in spite of the fact that the recent interest in sugar maple decline was sparked by unusually high levels of decline in the Muskoka region. The worsening condition of trees in the Peterborough area is also consistent with generally worsening, or at the best stable, condition of trees in the Peterborough area and to the east.

This trend toward increased improvement in Muskoka controls trees relative to those in Peterborough does not appear to be the result of the starting canopy condition of control trees in 1988. Although overall the control trees in Peterborough were in slightly greater decline than those in Muskoka in 1988 (DI = 25.05 and 22.24, respectively) there was a fairly even distribution in the mean starting condition of control trees across the four stands and the two areas. In addition, even the healthiest categories of trees in Peterborough (PUH) also declined from 1988 to 1990. Responses to fertilizer amendments in these areas must be considered relative to the background performance of control trees in these same locations.

Table 3.1 General trends in decline index for controls

LOCATION TAP DECLINE	DI88-DI89			DI88-DI90			DI89-DI90		
	Mean Difference*	T-Stat	P-value	Mean Difference*	T-Stat	P-value	Mean Difference	T-Stat	P-value
MTD	0.063	0.061	0.957	9.89	5.43	0.032*	9.820	6.10	0.026*
MTH	-0.539	-0.068	0.957	4.34	0.854	0.483	8.630	4.35	0.144
MUD	-0.430	-0.072	0.954	9.85	1.664	0.344	10.28	0.867	0.545
MUH	-6.75	-2.34	0.143	2.44	1.638	0.243	9.189	5.011	0.038*
PTD	-16.34	-3.053	0.202	-6.05	-0.786	0.576	10.29	0.789	0.575
PTH	2.307	0.835	0.492	6.277	2.438	0.135	3.970	0.904	0.462
PUD	0.365	0.094	0.934	-9.792	-0.576	0.623	-10.156	-0.743	0.535
PUH	-13.490	-3.289	0.081	-4.776	-0.856	0.482	8.713	2.349	0.143
Muskoka	-2.200	-1.129	0.288	6.337	3.417	0.007*	9.487	4.966	0.001*
Peterborough	-5.920	-1.959	0.079	-3.360	-0.704	0.497	2.560	0.550	0.595

* negative value indicates decline

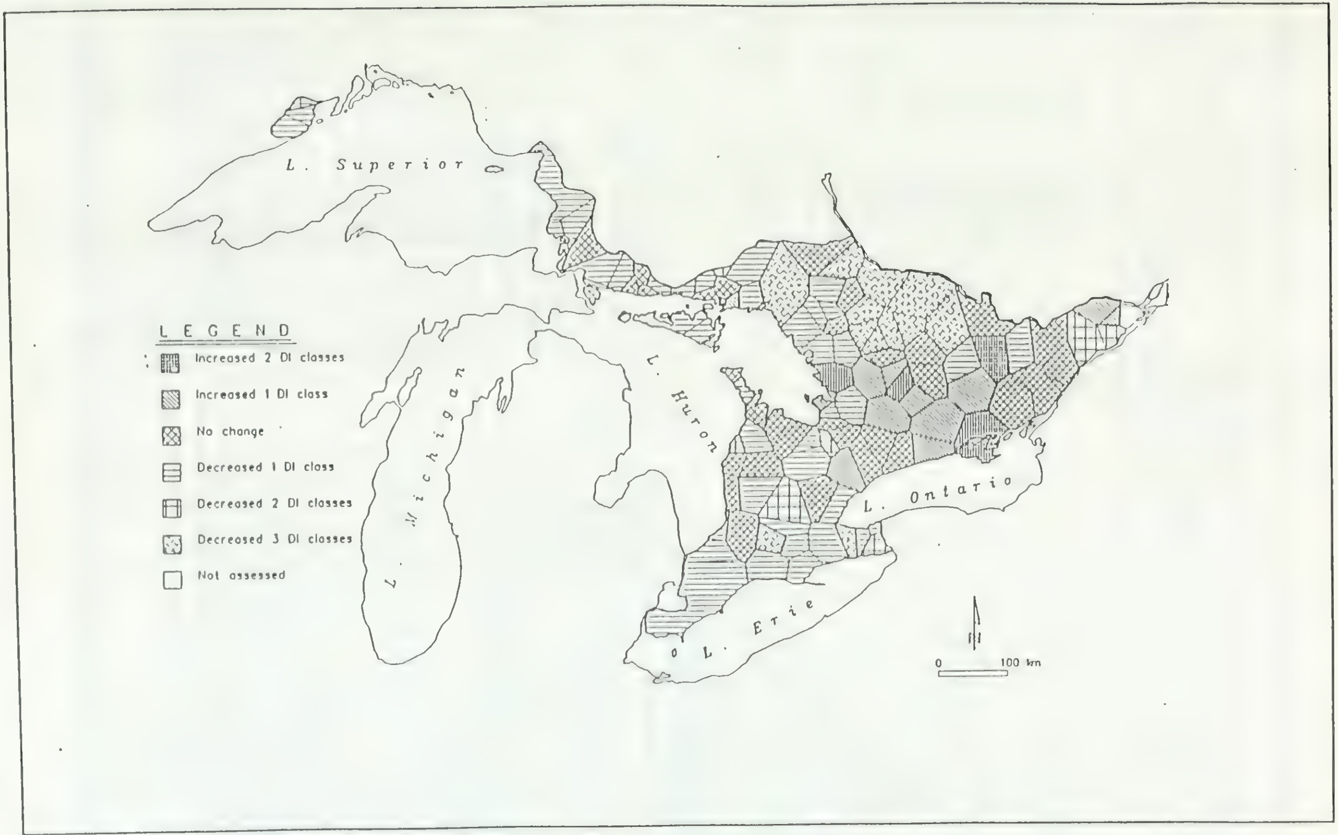


Figure 3.1 Decline index change 1987 to 1990

3.1.2 Planned Comparisons

The ANOVA for the difference in decline index between 1988 and 1990 is shown in Table 3.2. Note that location by tapping, decline and decline by location are the significant interactions ($p < 0.05$).

```
 LEVELS ENCOUNTERED DURING PROCESSING ARE:

 DEP VAR:  DIFF90      N:     183  MULTIPLE R: 0.611  SQUARED MULTIPLE
R: 0.373

                          ANALYSIS OF VARIANCE

 SOURCE       SUM-OF-SQUARES  DF  MEAN-SQUARE     F-RATIO       P

 L                    42.410   1       42.410       0.666     0.416
 T                    59.746   1       59.746       0.939     0.335
 L*T                 177.855   1      177.855       2.794     0.097+
 D                   935.755   1      935.755      14.700     0.000*
 F                   358.420   7       51.203       0.804     0.585
 D*F                 226.435   7       32.348       0.508     0.827
 D*L                 549.321   1      549.321       8.630     0.004*
 F*L                 680.515   7       97.216       1.527     0.164
 D*F*L               258.813   7       36.973       0.581     0.770
 D*T                   6.373   1        6.373       0.100     0.752
 F*T                 184.649   7       26.378       0.414     0.892
 D*F*T               477.845   7       68.264       1.072     0.385
 D*L*T                34.505   1       34.505       0.542     0.463
 F*L*T                71.501   7       10.214       0.160     0.992
 D*F*L*T             426.685   7       60.955       0.958     0.465
 ERROR              7575.029 119       63.656
 * p < 0.05,   + p < 0.1
```

Table 3.2 ANOVA for difference in Decline Index 1988-1990

The ANOVA for the difference between 1988 and 1989 decline index was presented and discussed in a previous report (MOE, unpubl.). The results of the planned comparisons involving responses in canopy condition (relative to control response) between 1988 and 1990 are shown in Tables 3.3 to 3.5. For the reader's convenience standard errors (S.E.) are provided for purposes of contrasting control corrected responses. They can be used to compute t-statistics (t = Difference/S.E.) used to compute p-values in a t distribution table at 119 degrees of freedom. Positive responses indicate an improvement in canopy condition during the two year period. Results of planned comparisons are discussed below.

The results of planned comparisons for treatment responses in decline index averaged over all locations are presented in Table 3.3. There is a general trend toward improvement in canopy condition in response to all fertilizer treatments. However, the only significant ($p < 0.05$) fertilizer treatment over all locations is the combined treatment (T). Nitrogen and calcium also result in overall (but not significant) improvements in canopy condition.

TREATMENT	CONTROL CORRECTED RESPONSE	P-VALUE*
Ca	2.8	0.11
K	2.2	0.18
L	1.9	0.20
Mg	1.5	0.25
N	3.6	0.07
P	2.1	0.17
T	4.5	0.03*

S.E. (Response vs control) = 2.3
Mean of fertilizer treatment - Control

Table 3.3 Planned comparisons over all locations*

Since there is a general positive response to all treatments, this suggests that all components of the combined amendment are probably contributing to the treatment response.

Improvements in canopy condition in response to the combined and nitrogen treatments were also noted in 1989 although they were not significant (MOE, unpubl.). This suggests a response to the total and nitrogen treatments which are evolving over the longer term and which may continue to produce responses over the years. Mader and Thompson (1969) found that nitrogen fertilization ameliorated canopy decline and growth suppression in declining maple stands.

Location specific responses in canopy condition to fertilization are summarized in Table 3.4. The responses presented in this table represent the control corrected response of the two stands (tapped and untapped) in each location. Response to all fertilizers in Peterborough were consistently positive and with the exception of magnesium statistically higher ($p<0.05$) than the response in Muskoka stands. The overall treatment response in Peterborough was significantly greater than that for Muskoka. This pattern is consistent with that found in 1989 (MOE, unpubl.) for the total and nitrogen amendments. The results again suggest that the overall response to the complete nutrient amendment described earlier was due to the response on Peterborough rather than Muskoka stands. Interestingly, the Peterborough stands also supported greater responses to the lime and calcium treatments. The opposite trend was expected due to the calcareous parent material associated with the Peterborough area and the resulting elevated pH and available calcium in soils of the area. However, this pattern was consistent with that found in 1989 (MOE, unpubl.). It is important to re-emphasize that the improvements resulting from fertilization in Peterborough occur against a background of deteriorating canopy condition in the area.

TREATMENT	CONTROL CORRECTED RESPONSE		P-VALUE FOR DIFFERENCE
	MUSKOKA	PETEB-OROUGH	
Ca	-3.7	9.3	0.006
K	-2.3	6.7	0.025
L	-3.1	6.9	0.02
Mg	-1.9	4.8	0.07
N	-2.2	8.5	0.01
P	-5.1	8.0	0.002
T	-0.7	10.1	0.01
OVERALL	-2.7	7.7	0.000

S.E. (within location) = 3.25
S.E. (difference Muskoka - Peterborough) = 4.6

Table 3.4 Planned comparisons by location

In contrast, responses to fertilizer applications in Muskoka were consistently negative. The positive responses to calcium and magnesium (although not significant) which were noted for the Muskoka stands for 1989 were not evident in 1990 (MOE, unpbul.). This suggests that these positive response which were predicted for these amendments on the acidic and base poor soils were either not real responses in canopy health (i.e. the result of observer error) or were not persistent in terms of longterm impacts on visual canopy health symptoms.

Table 3.5 summarizes planned comparisons by decline status. It would be expected that declining stands and/or trees would demonstrate a greater response to fertilization than healthy trees if the element added was deficient or related to the underlying cause of the decline. A number of studies have documented differences in the response of healthy and declining stands to nutrient amendments (Hendershot and Jones, 1989; Kinch, 1989). Similarly, in this study all fertilizer amendments resulted in positive responses in canopy condition across all for declining trees. For all treatments except lime the declining trees responded more than the healthy trees, however the difference in these responses was not significant. In contrast, responses of healthy trees to all but two amendments (Ca and Total) were negative relative to the control.

TREATMENT	CONTROL CORRECTED RESPONSE		P-VALUE
	DECLINING	HEALTHY	
Ca	6.0	0.2	0.1
K	5.8	-0.8	0.07
L	4.4	-0.6	0.15
Mg	4.5	-1.6	0.09
N	8.2	-0.2	0.03
P	5.8	-1.0	0.1
T	8.1	1.1	0.06
OVERALL	6.1	-0.4	0.000

S.E. (within location) = 3.25
S.E. (difference declining - healthy) = 4.6
S.E. (overall difference) = 1.7

Table 3.5 Planned comparisons by decline status

The superior response of declining trees to fertilization was more striking for the Peterborough stands where the control corrected difference between declining and healthy trees was large with a p value of 0.018. For Muskoka the difference between response of healthy and declining trees to fertilization was not nearly significant (p=0.752).

Therefore, the most significant findings of planned comparisons were the following:

1) Overall fertilizer amendments resulted in mean improvements in canopy condition.

2) Overall the total fertilizer treatment resulted in the greatest improvement in growth followed by calcium and nitrogen.

3) Mean regional responses to fertilizers in Peterborough were consistently positive and except in the case of magnesium were statistically higher in Peterborough as compared to Muskoka.

4) Responses to fertilizer applications in Muskoka were consistently negative when considered relative to the response of the control in this region.

5) The overall responses of declining trees to fertilizer treatments were consistently positive and higher than those of healthy trees.

6) The overall superior response of declining trees to fertilization was driven by the response of declining trees in Peterborough.

3.1.3 Tests on Effects Suggested By the Data

The following section summarizes the results of further examination of the data to investigate patterns not covered by planned comparisons. This would include within region adherence to the trends uncovered by the planned contrasts described above. This was accomplished by allowing significant terms in the ANOVA to direct contrasts and data investigation.

TREATMENT	MUSKOKA		PETERBOROUGH		MEAN
	TAPPED (MT)	UNTAPPED (MU)	TAPPED (PT)	UNTAPPED (PU)	
CA	-4.4	-3.1	8.7	9.9	2.8
K	-3.0	-1.7	3.7	10.4	2.2
L	-3.1	-3.0	4.2	9.7	1.9
MG	-2.1	-1.7	2.1	7.6	1.5
N	-3.3	-1.2	5.7	11.2	3.6
P	-5.1	-5.1	5.7	10.3	2.1
T	-3.0	1.6	7.3	13.4	4.5
MEAN	-3.4	-1.9	5.3	10.3	2.6

PU-MT = 0 p = 0.006 PT-MT = 0 p = 0.04
PU-MU = 0 p = 0.01 PT-MU = 0 p = 0.07
PU-PT = 0 p = 0.15
S.E. (for comparing treatment means within location i.e. MUSKOKA TAPPED) = 4.6
S.E. (for comparing treatment means under MEAN column heading) = 2.3
S.E. (for comparing treatment means between locations i.e. Ca MT - Ca M U = 0) = 6.5
S.E. (for comparing locations averaged over location (i.e. mean MT - mean MU = 0) = 4.9

Table 3.6 Location by tapping means(control corrected) over all treatments

The first significant interaction term in the ANOVA (Table 3.1) was location by tapping. This is of course a surrogate for physical location. The responses to fertilization at the level of the physical location of the stand are summarized in Table 3.6. As described earlier the overall response to fertilization in Peterborough stands far exceeded that in Muskoka. After correcting for control, the overall response to fertilization of trees in the Peterborough untapped stand was significantly better than the response of trees in both the Muskoka tapped and untapped stands. The overall response to fertilization for the Peterborough tapped stand was also substantially higher than the responses for the Muskoka tapped plot but not significantly higher than the Muskoka untapped site.

It was noted earlier, that, after correcting for control, declining trees responded more positively to fertilizer treatment than healthy trees when considering all trees in the study ($p=0.139$). It was also noted earlier that the largest difference between declining and healthy trees by region (L*D) was in Peterborough. This is illustrated in table 3.7. Indeed there was significantly greater overall response to fertilization among the Peterborough declining trees as compared to the healthy ones ($p=0.018$). Comparing the individual treatments between Peterborough declining and healthy tree, K, L and N were significant at ($p<0.05$) while the others had P values between 0.05 and 0.1.

Examination of data for the two Peterborough sites (Table 3.8) indicated that the Peterborough tapped site was principally responsible for the difference between declining and healthy fertilizer response. The responses of declining trees to individual fertilizers at the Peterborough tapped site were statistically ($p < 0.05$ see table 3.9) superior to healthy trees for all fertilizer amendments except Mg. For these declining trees the mean response of all treatments compared with the healthy trees was significantly higher ($p = 0.02$). In contrast, the Peterborough untapped site had no significant control corrected comparisons between healthy and declining trees.

TREATMENT	MUSKOKA		PETERBOROUGH		MEAN
	DECLINE	HEALTHY	DECLINE	HEALTHY	
CA	-2.9	-4.3	14.9	4.7	2.8
K	-3.0	-1.7	14.7	0.1	2.2
L	-3.8	-2.3	12.7	1.2	1.9
MG	0.2	-4.0	8.8	0.9	1.5
N	-1.0	-3.1	14.3	2.7	3.6
P	-5.2	-5.0	13.1	2.9	2.1
T	1.8	-3.2	15.8	5.4	4.5
MEAN	-1.9	-3.4	13.3	2.5	2.6

S.E. (for comparing treatment means within decline category) = 4.6
S.E. (for comparing treatment means for MEAN column) = 2.3
S.E. (for comparing treatment means between decline categories) = 6.5
S.E. (for comparing locations averaged over decline category) = 4.9

Table 3.7 Control corrected response for region and decline status by treatment

It is instructive to further examine the table of control corrected responses for all stands and decline categories (Table 3.8). The greater than and less than signs indicate when a response of healthy trees is greater than or less than that of declining trees. The majority of greater responses to treatment occurred for declining trees (21) as compared to only 7 greater responses for healthy trees. All but one of the greater responses associated with healthy trees occurred on Muskoka stands.

There is little apparent consistency in fertilizer response from site to site. For example, while fertilizer responses in the Peterborough region were strong, no specific fertilizer or fertilizers consistently resulted in improvements in canopy condition for both healthy and declining trees in both locations within the region. There were also unexpected responses to treatments. For example, one of the original reasons for dividing the study into Muskoka and Peterborough regions was to examine fertilizer response which may have been related to soil acidity. One original hypothesis was that lime would have a positive impact on tree health in Muskoka and less if any impact in Peterborough. The data actually indicated the opposite, with Peterborough responding more positively than Muskoka to lime application. A similar pattern was present for calcium. These counter intuitive responses were especially evident for the tapped stand in Peterborough. This stand had a high baseline soil pH and calcium concentration with a pH of over 6 and an exchangeable calcium concentration of over 17 ppm. In Muskoka, for example, lime had no influence on declining trees at the tapped stand in Muskoka but a trend toward negative impact on declining trees in the untapped stand (Table 3.8).

To summarize there are:

- significant differences in the response of Muskoka and Peterborough trees to fertilizer treatments with the Peterborough trees showing a significantly greater response

- declining trees show greater response to fertilizers than healthy trees but only significantly ($p<0.05$) at the Peterborough tapped site.

Therefore, although there were a number of clear trends revealed in the data when examining planned comparisons across locations, decline status and/or across all factor levels within the design, the trends were not consistent at the individual stand level. Fertilizer responses appear to be a site specific phenomena.

TREATMENT	P-VALUE
Ca	0.008
K	0.01
Lime	0.04
Mg	0.17
N	0.04
P	0.03
Total	0.025
Overall	0.02

Table 3.9 P values for difference between Peterborough tapped declining and healthy control corrected responses.

Table 3.8 Control corrected mean difference in decline index for region, tapping and decline status by fertilizer treatment.

TREATMENT	MUSKOKA						PETERBOROUGH						MEAN OF ROWS
	TAPPED			UNTAPPED			TAPPED			UNTAPPED			
	DECLINE		HEALTHY	DECLINE		HEALTHY	DECLINE		HEALTHY	DECLINE		HEALTHY	
CA	0.5	>	-7.6	-5.2	<	-1.0	22.5	>	-0.5	9.8	<	10.0	2.8
K	-6.1	<	-0.9	-1.0	>	-2.5	14.9	>	-7.5	14.4	>	7.7	2.2
L	0.7	>	-6.9	-8.3	<	2.3	12.3	>	-4.0	13.0	>	6.3	1.9
MG	2.3	>	-6.5	-1.9	<	-1.5	6.4	>	-2.2	11.2	>	4.0	1.5
N	-5.5	<	-1.9	3.5	>	-4.2	13.7	>	-2.2	14.9	>	7.5	3.6
P	-6.7	<	-3.9	-3.7	>	-6.0	13.9	>	-2.5	12.2	>	8.3	2.1
T	-1.4	>	-4.7	5.0	>	-1.7	14.6	>	0.1	17.5	>	10.7	4.5
MEAN OF COLUMNS	-1.8		-4.6	-1.8		-2.1	13.6		-2.7	13.0		7.8	2.6
> Total		4			4			7			6		
< Total		3			3			0			1		

S.E. (for comparing treatment means within decline status (i.e. within MUSKOKA TAPPED DECLINE column) = 6.5

S.E. (for comparing treatment means under MEAN column heading) = 2.3

S.E. (for comparing treatment means between decline status columns) = 9.2

S.E. (for comparing MEAN OF COLUMNS ROW) = 7.0

3.1.4 Decline Index Components

ANOVA's were performed on the four components of the decline index (DI). The P-values and mean square errors for these ANOVA's are shown in table 3.10. The equation for DI is shown in section 2.2.

Table 3.10 P-Values for ANOVA for decline index and its components.

SOURCE	DECLINE INDEX	PERCENT DEAD BRANCHES	PERCENT UNDERSIZED LEAVES	PERCENT STRONG CHLOROSIS	PERCENT SLIGHT CHLOROSIS
L	0.416	0.005	0.000	0.002	0.000
T	0.355	0.285	0.583	0.516	0.192
L*T	0.097	0.065	0.223	0.190	0.063
D	0.000	0.117	0.000	0.000	0.000
F	0.585	0.554	0.174	0.988	0.662
D*F	0.827	0.639	0.379	0.404	0.443
D*L	0.004	0	0.002	0.028	0.203
F*L	0.164	0.159	0.402	0.142	0.080
D*F*L	0.770	0.781	0.663	0.334	0.366
D*T	0.752	0.21	0.000	0.977	0.444
F*T	0.892	0.94	0.381	0.625	0.415
D*F*T	0.385	0.586	0.479	0.171	0.152
D*L*T	0.463	0.248	0.094	0.322	0.588
F*L*T	0.992	0.972	0.248	0.413	0.513
D*F*L*T	0.465	0.392	0.429	0.492	0.824
Mean Square Error	63.656	60.413	32.719	66.682	99.268

Referring to this equation it would be expected that percent dead branches would dominate the decline index calculation and indeed it does (see figure 3.2). In figure 3.2, the percent contribution of each component of the 1990 decline index was graphed for each tree. The trees were sorted from lowest contribution for dead branches to highest. In the 1990 decline index calculation, dead branches accounts for 85 percent of the decline index with 11, 3 and 1 percent for slight chlorosis, noticeable chlorosis and undersized leaves respectively.

Referring to table 3.11 for the control corrected responses of the 4 decline index calculation parameters it can be seen how closely decline index parallels dead branches. The data in table 3.11 is shown graphically in Figure 3.3. It is apparent from figure 3.3 that health status parameters may in some cases show opposite tendencies. In particular, at the Peterborough tapped site , declining trees show a decrease in percent dead branches and an increase in all the other parameters. There is a significant difference in undersized leaves (p=0.03) between Peterborough tapped declining and healthy trees. This really contradicts the significant health increases indicated by decline index shown in tables 3.8 and 3.9.

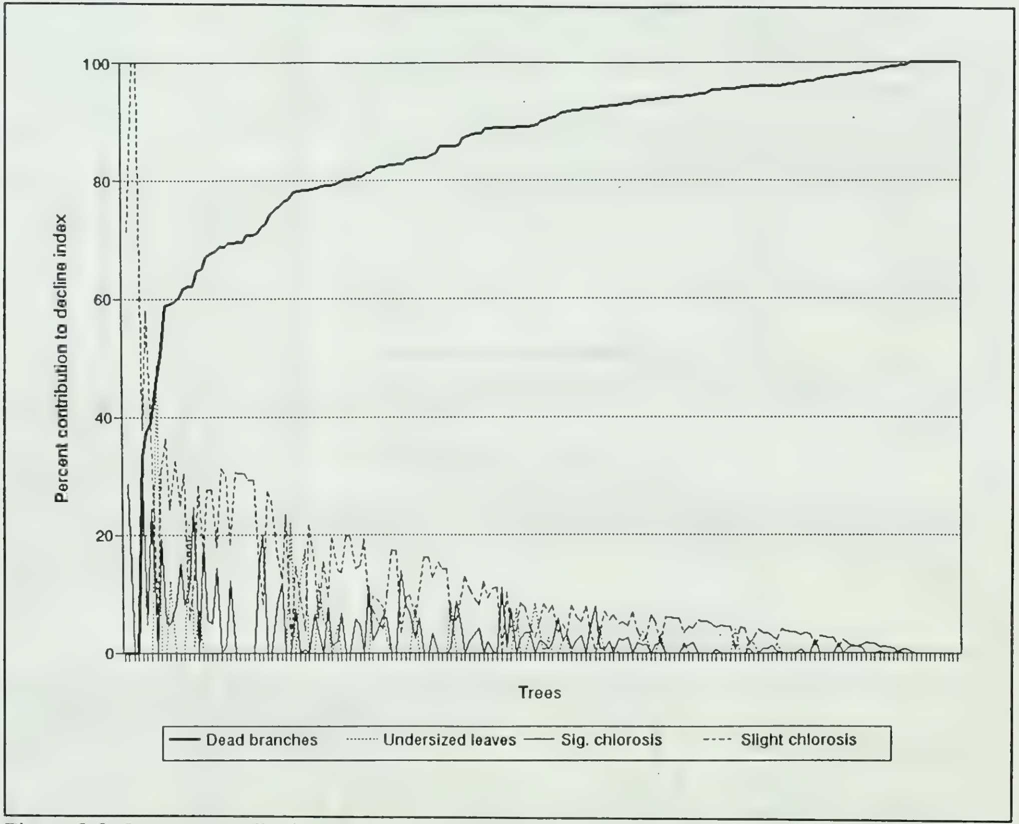


Figure 3.2 Percent contribution of each component to decline index for each tree for 1990

Table 3.11 Control corrected response for decline index and parameters used to compute decline index (1988 - 1990)

TEST	MUSKOKA				PETERBOROUGH				MEAN OF ROWS	STANDARD ERROR (d.f = 21)
	TAPPED		UNTAPPED		TAPPED		UNTAPPED			
	DECLINE	HEALTHY	DECLINE	HEALTHY	DECLINE	HEALTHY	DECLINE	HEALTHY		
Decline index	-1.8	-4.6	-1.5	-2.1	13.6	-2.7	13.0	7.8	2.7	7.0
% dead branches	-3.5	-4.7	-2.8	-2.3	14.9	-1.5	11.8	6.4	2.3	6.8
% slightly chlorotic	9.6	-1.3	0.5	0.2	-3.8	-1.0	6.3	11.1	2.7	5.0
% significantly	3.3	-0.3	4.9	0.9	-5.4	-1.3	5.0	1.7	1.1	7.1
% undersized	-0.3	0.2	-1.4	0.0	-12.8	-3.8	-3.0	-1.1	-2.8	8.7

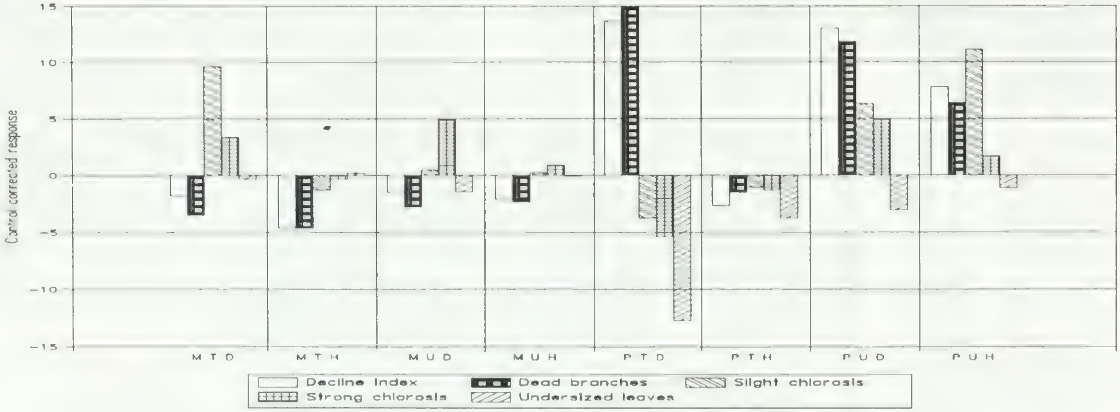


Figure 3.3 Control corrected response for decline index and parameters used to compute it (1988 minus 1990)

3.2 Soil and Tree Chemistry and Decline

We know, from the ANOVA of decline index presented in section 3.1, that there were significant changes in DI due to the combined treatment and significant differences in response between declining and healthy trees. This difference between the response of declining and healthy trees prompts the question: How does soil and foliar chemistry relate to decline index?

The following summarizes the results of data relating soil and foliar chemical status of sample trees and the relationship between baseline chemistry and tree health.

3.2.1 General Examination of Baseline Soil and Tree Chemistry

Baseline soil and foliar chemical parameters are presented in table 3.9 and 3.10 (see Appendix A for a detailed breakdown by region, decline status, tapping status and treatment for 1988 and 1989). As discussed earlier tapping status is also a surrogate for physical stand location within a region and many responses within a region appeared to be location specific.

Within the Muskoka region the tapped stand had lower concentrations of aluminum in soil extracts, higher concentrations of calcium and magnesium and higher soil pH than the untapped stands (Table 3.12). The healthy trees in the tapped stand also had higher levels of most soil parameters than declining trees in the same stand. However, the reverse was true for the untapped stand where healthy trees had lower levels of all soil parameters measured (including pH) except for calcium.

Foliar chemistry in the Muskoka stands loosely approximates the patterns described above for soil chemistry. With few exceptions the concentrations of the elements tested were consistently higher in trees of the tapped stand as compared to the untapped stand (Table 3.13). In addition, healthy trees in the untapped stand also had lower levels of a number of elements including B, Ca, Mn, Mo, N, Zn and S as compared to declining trees. However, the consistently lower levels of elements found in the soils of declining trees at the tapped stand was not consistently reflected in the results of foliage chemistry. In addition, for no element was there a consistent suppression in the declining trees across the region.

Table 3.12 Baseline 1988 soil chemistry

TEST	MUSKOKA				PETERBOROUGH				MEAN
	TAPPED		UNTAPPED		TAPPED		UNTAPPED		
	DECLINING	HEALTHY	DECLINING	HEALTHY	DECLINING	HEALTHY	DECLINING	HEALTHY	
ALECA	6.27	6.50	20.67	18.69	0.29	0.28	1.11	0.76	6.88
ALESC	1.20	1.12	2.50	2.27	0.01	0.02	0.05	0.04	0.91
CAESC	5.68	7.14	2.52	1.98	17.72	17.70	16.59	14.40	10.38
KKESC	0.23	0.27	0.23	0.17	0.24	0.27	0.13	0.13	0.21
MGESC	0.66	0.88	0.32	0.25	0.63	0.63	0.84	0.74	0.62
ORGC	6.95	8.18	9.86	7.08	3.91	4.13	4.75	4.67	6.21
PHECA	4.16	3.97	3.78	3.70	6.29	6.24	5.32	5.27	4.83
PHEW	4.70	4.43	4.21	4.11	6.87	6.75	5.73	5.71	5.30
PPO4BE	14.03	16.18	8.06	7.87	75.38	77.79	18.02	14.53	28.74
SNITRO	4.27	5.15	5.23	3.87	2.41	2.91	3.04	2.96	3.74
SPPUT	0.80	0.92	0.81	0.67	0.85	1.03	0.60	0.50	0.77
SSO4EW	25.99	23.88	27.48	22.38	33.01	34.13	41.60	24.75	29.28
TIC	0.01	.	.	.	0.04	0.07	0.03	0.01	0.04

Table 3.13 Baseline 1988 foliar chemistry

TEST	MUSKOKA				PETERBOROUGH				MEAN
	TAPPED		UNTAPPED		TAPPED		UNTAPPED		
	DECLINING	HEALTHY	DECLINING	HEALTHY	DECLINING	HEALTHY	DECLINING	HEALTHY	
ALUT	33.55	30.73	24.64	21.65	36.26	39.46	34.38	33.41	31.75
BBUT	84.49	73.71	59.70	44.04	59.63	67.76	55.10	73.74	64.82
CAUT	9808.33	10016.67	6261.43	6001.39	16071.43	15847.22	15050.00	15720.55	11858.64
CLUT	0.02	.	0.00	0.00	0.01	0.01	.	.	0.01
CUUT	11.46	8.36	6.97	7.50	7.20	7.69	7.32	7.59	7.99
FEUT	72.83	63.67	51.23	50.72	62.06	68.19	67.76	64.93	62.67
KKUT	0.91	.	.	.	0.86	0.88	.	.	0.88
MGUT	1397.64	1374.72	921.43	959.44	1838.71	1761.11	1961.81	1895.89	1515.45
MNUT	617.36	518.43	925.43	822.92	126.59	123.31	210.74	131.97	433.43
MOUT	0.30	0.37	0.30	0.16	0.42	0.40	0.44	0.30	0.34
NAUT	143.46	155.27	57.60	61.40	101.47	96.92	106.47	124.67	105.95
NIUT	1.71	1.27	1.04	1.07	0.33	0.28	0.83	0.28	0.84
NNTKUR	21.49	22.51	20.32	19.91	16.04	15.90	21.03	20.01	19.66
PPUT	1.29	1.30	1.21	1.13	2.34	2.48	1.44	1.16	1.54
SSUT	0.19	.	0.10	0.13	0.19	0.19	.	.	0.16
ZNUT	36.46	25.42	23.90	21.93	12.49	10.71	14.89	14.32	20.02

The untapped stand in Peterborough had higher concentrations of soil aluminum, calcium and magnesium, lower concentrations of soil potassium and phosphorus and lower pH than the tapped stand. The most consistent response to fertilization and liming occurred on the untapped stand in this region. The strong positive response of declining trees in the tapped stand to calcium application is consistent with the suppressed levels of calcium in soils around these trees relative to the untapped stand. However, it is difficult to understand the response on these soils which have a relative abundance of free calcium as compared to the Muskoka stands which in turn did not respond well to the same application. While the strongest overall responses to fertilization in the region occurred for declining trees these trees tended to be associated with higher concentrations of both soil and foliar nutrients prior to fertilization than healthy trees. The only element which was consistently lower in the soil and foliage of declining trees was total phosphorus. Copper and boron in foliage were also consistently lower in the foliage of declining trees as compared to healthy trees in Peterborough. At the untapped stand all soil elements except phosphorus were lower beneath healthy trees compared to declining trees. The reverse was true for the tapped stand.

It would therefore appear that while some fertilizer responses were consistent with baseline soil and foliar chemistry many seem not to be and require further investigation.

3.2.2 T-Test on Healthy and Declining Foliar and Soil chemistry

The ANOVA for decline index showed significant differences in the response of declining and healthy trees to fertilizer treatments. It is of interest to examine the difference between the soil and foliar chemistry for healthy and declining trees. The 1988 soil and foliar chemistry data represents a baseline 'before fertilization' sample of chemistry. A T test for two independent samples was applied to the means of soil and foliar chemistry for declining and healthy trees to test the hypothesis that the mean chemistry values for healthy trees and declining trees were the same. The P-values for the T statistics for foliar and soil chemistry are shown in tables 3.14 and 3.15 respectively.

The results are inconsistent. Elevated foliar metals tend to be associated with decline at the Muskoka sites which is consistent with theories on soil acidification (table 3.14). At the Peterborough tapped site, in a high Ca soil, there is significant relationship between low boron and iron and decline (table 3.11). According to Baule, 1970 high calcium soils can lead to boron and iron deficiencies. However, the calcium treatment led to the greatest improvement in declining trees at the Peterborough tapped site.

Elevated levels of all soil chemistry parameters are associated with decline at the two untapped sites (table 3.15).

3.2.3 Scatter Plot Matrices

Scatter plot matrices illustrating relationships between baseline soil and foliar chemistry and decline index for each site are presented in Figures 3.4 to 3.7. These matrices provide a convenient screening level summary of the majority of chemical parameters in the data.

It is instructive to note the lack of strong linear relationship between decline index and individual foliar and/or soil variables. Although generally relationships were weak and variability in the relationships between individual soil and foliar variables and decline index was high it appears that overall relationships between soil and foliar parameters and decline index were stronger for Muskoka stands as compared to Peterborough stands. While a general consideration of soil and foliar chemistry indicated that the Muskoka stands were comparatively nutrient poor, responses in decline index to fertilization were unexpectedly weak for these stands (see Section 3.2.1).

TEST	MUSKOKA		PETERBOROUGH	
	TAPPED	UNTAPPED	TAPPED	UNTAPPED
ALUT	-0.1	-0.0005	0.05	-0.25
BBUT	-0.0005	-0.0005	0.0005	0.0005
CAUT	0.4	-0.25	-0.4	0.15
CDUT	.	.	.	.
CLUT	.	0.1	0.05	.
CUUT	-0.0005	0.05	0.05	0.2
FEUT	-0.005	-0.4	0.025	-0.1
KKUT	.	.	0.4	.
MGUT	-0.4	0.2	-0.1	-0.2
MNUT	-0.025	-0.05	-0.4	-0.0005
MOUT	0.01	-0.0005	-0.25	-0.0005
NAUT	0.2	0.25	-0.4	0.01
NIUT	-0.005	0.4	-0.025	-0.0005
NNTKUR	0.025	-0.25	-0.4	-0.05
PPUT	0.4	-0.025	0.05	-0.0005
SSUT	.	0.001	.	.
ZNUT	-0.0005	-0.05	-0.005	-0.25

* Negative value implies inverse relationship i.e. higher aluminum associated with decline

Table 3.14 P-values for T-test for foliar chemistry (healthy vs declining)*

Strong linear relationships were apparent between soil parameters and between foliar parameters. For example, there were strong negative relationships between soil aluminum concentration and soil calcium, magnesium and pH at the Muskoka tapped site. However, these relationships were weak for the Muskoka untapped site and, as expected due to the high soil pH, not evident for the Peterborough sites. Perhaps the most consistent and strong relationship occurred between exchangeable soil calcium and magnesium and to a lesser extent between exchangeable calcium and pH. The strongest relationships between foliar parameters occurred at the Muskoka untapped site with strong relationships between phosphorus and nitrogen, calcium and magnesium and between boron and both calcium and magnesium. Relationships between foliar parameters were weak for the trees at the Peterborough stands.

Relationships between soil and foliar chemistry were extremely weak for the Muskoka untapped and Peterborough tapped stand. Relatively strong and positive relationships were evident at the

Muskoka tapped stand between soil nitrogen and foliar phosphorus and aluminum and between soil sulphate and foliar phosphorus and aluminum. At Peterborough fairly strong positive relationships were evident for exchangeable magnesium versus foliar aluminum and calcium. Negative relationships were apparent for foliar nitrogen and both soil nitrogen and calcium at the same site.

Therefore, the relationships between individual soil and foliar chemistry parameters and decline index were generally weak prior to fertilization. While strong relationships did exist for certain foliar and soil variables they were usually site specific.

TEST	MUSKOKA		PETERBOROUGH	
	TAPPED	UNTAPPED	TAPPED	UNTAPPED
ALECA	0.4	-0.15	-0.005	-0.01
ALESC	-0.3	-0.05	0.0005	-0.3
CAESC	0.025	-0.05	-0.005	-0.05
KKESC	0.05	-0.0005	0.25	-0.2
MGESC	0.005	-0.005	-0.005	-0.1
ORGC	0.05	-0.0005	0.15	-0.005
PHECA	-0.005	-0.05	-0.3	-0.4
PHEW	-0.0005	-0.025	-0.1	-0.005
PPO4BE	0.3	-0.005	0.4	-0.025
SNITRO	0.005	-0.0005	0.0005	-0.4
SPPUT	0.05	-0.05	0.0005	-0.005
SSO4EW	-0.2	-0.005	0.005	-0.0005
TIC	.	.	0.1	-0.15

* Negative value implies inverse relationship i.e. higher aluminum associated with decline

Table 3.15 Significance levels for T-test for soil chemistry (healthy vs declining)*

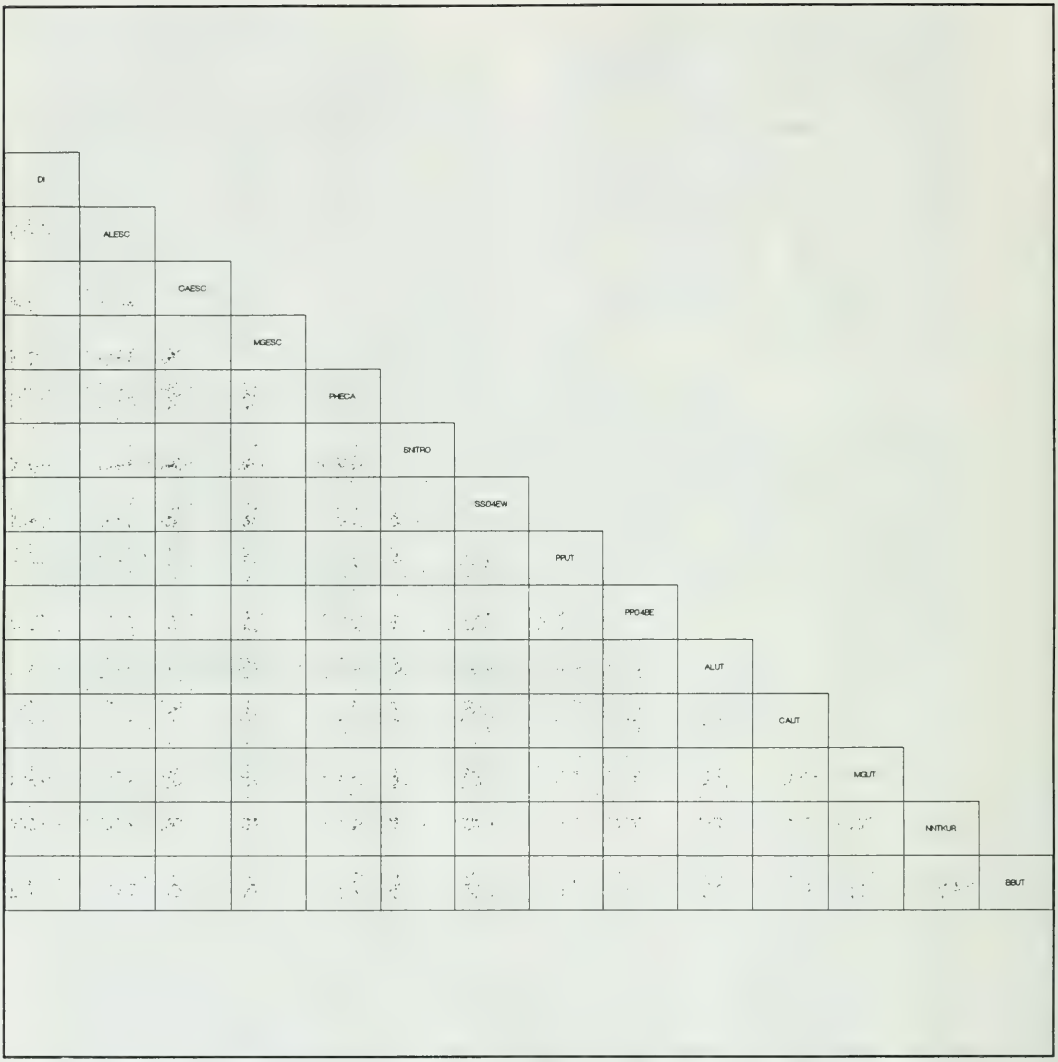


Figure 3.4 Scatterplot matrix of 1988 Muskoka untapped decline index and select foliar and soil chemistry parameters

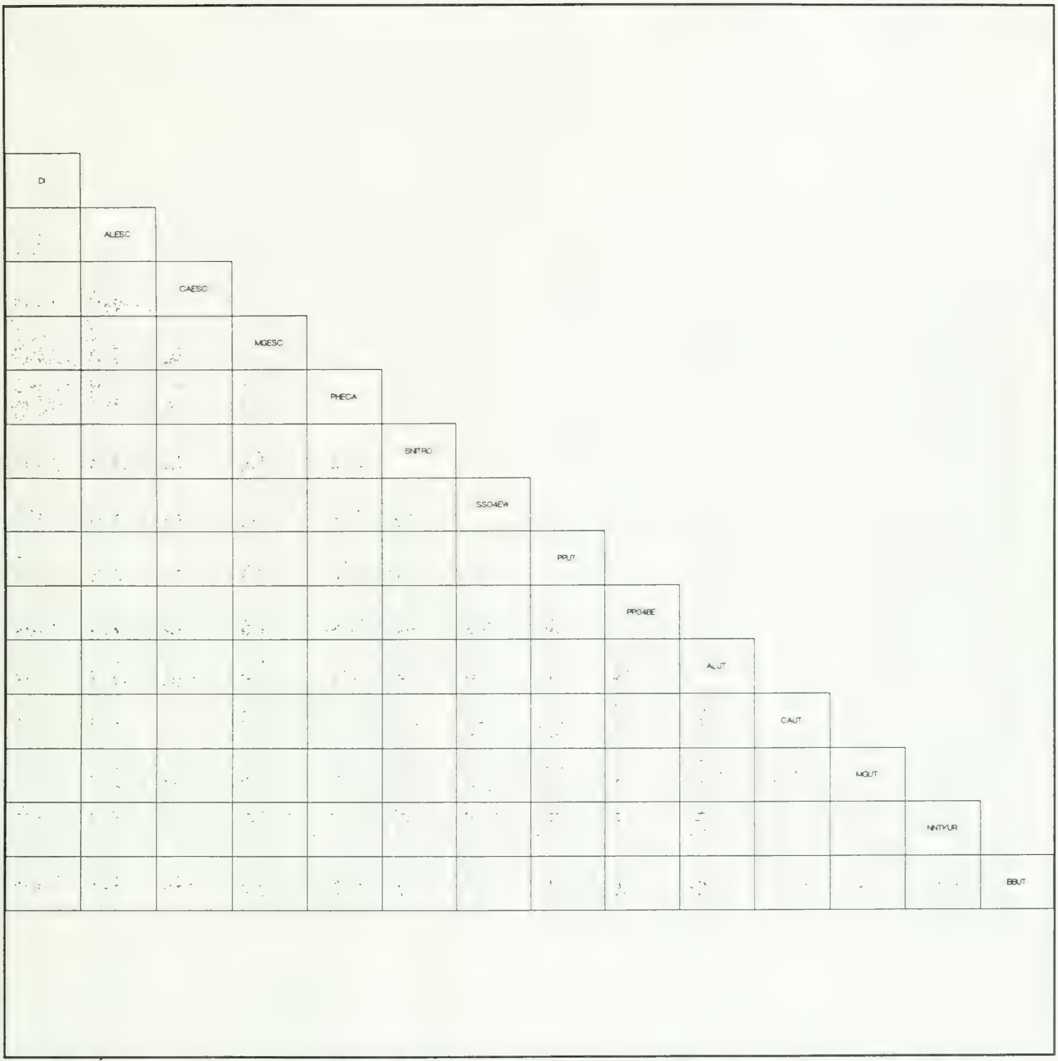


Figure 3.5 Scatterplot matrix of 1988 Muskoka tapped decline index and select foliar and soil chemistry parameters

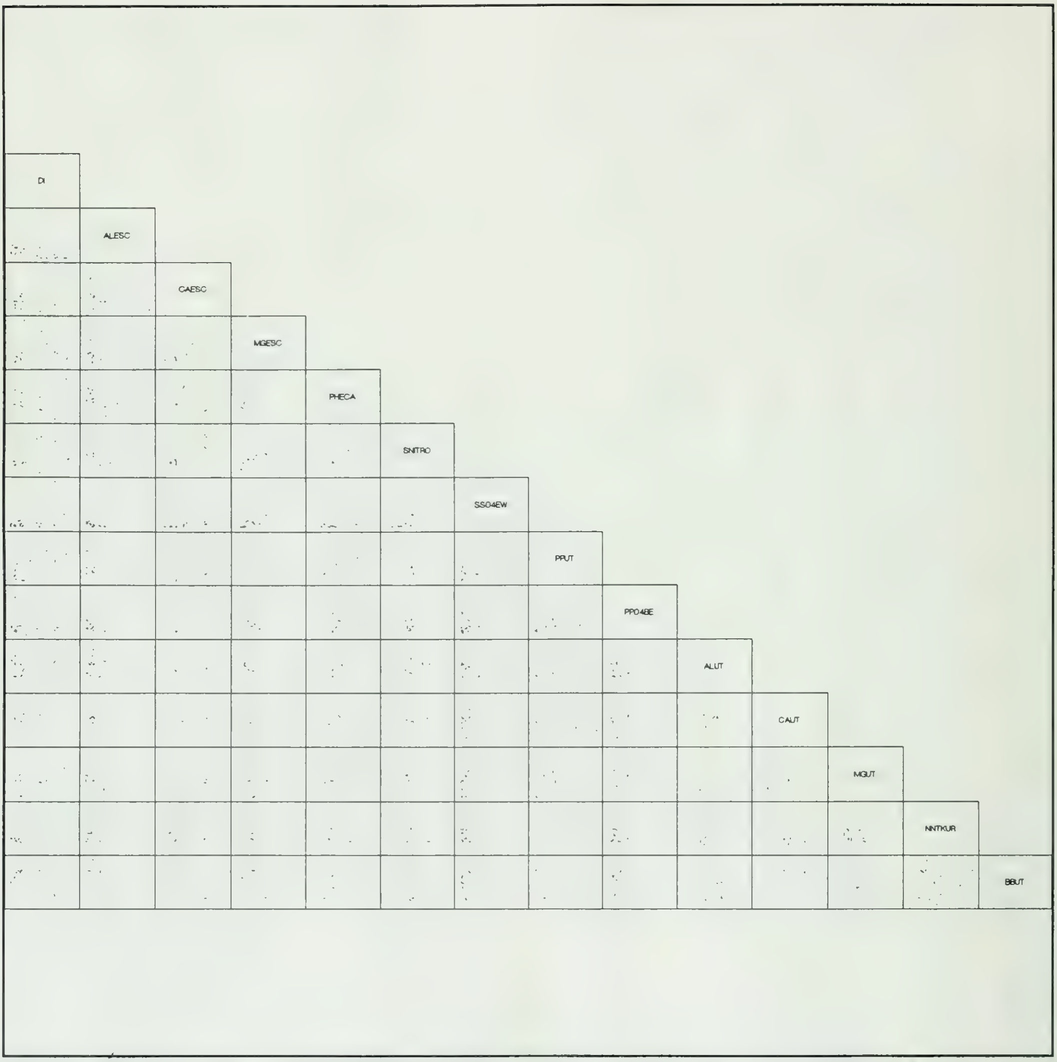


Figure 3.6 Scatterplot matrix of 1988 Peterborough untapped decline index and select foliar and soil chemistry parameters

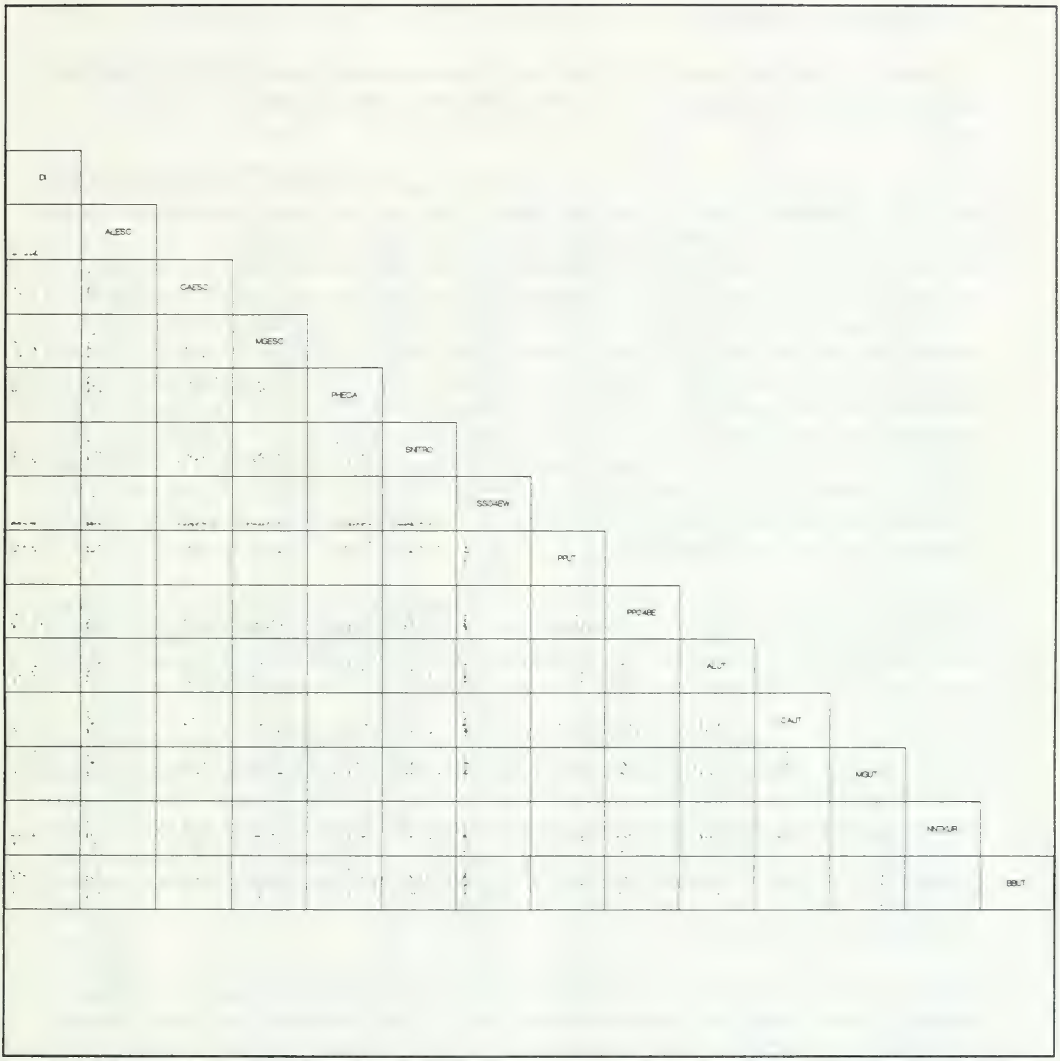


Figure 3.7 Scatterplot matrix of 1988 Peterborough tapped decline index and select foliar and soil chemistry parameters

3.2.4 Canonical Correlation

The results of canonical analysis examining the relationship between canopy variables, including decline index, and soil variables for Muskoka and Peterborough are summarized in Tables 3.16 and 3.17.

The first two canonical correlations were significant for the Muskoka site (p=0.0001 and p=0.0001, respectively) and are discussed below. Foliar variables strongly correlated with the first soil variate were Al (R=0.68), B (R=0.61), Ca (R=0.84), Mg (R=0.81), Na (R=0.82) and Mn (R=-0.62) (Table 3.16). The first soil variate was characterized by strong negative weightings of soil pH, exchangeable magnesium and calcium and exchangeable aluminum. The results indicate that soils in Muskoka with low pH have correspondingly low levels of base cations and elevated aluminum concentrations. This combination of soil variables was not strongly correlated with decline index and was negatively correlated with foliar concentrations of foliar calcium, magnesium, boron and aluminum. This first set of canonical loadings emphasizes the weak relationship between soil and foliar chemistry and decline index. The negative relationship between soil cations and pH and foliar elements is difficult to understand. Therefore, while there is a fairly strong relationship between soil pH and soil cations and aluminum the relationship between groupings of soil variables and foliar variables is generally weak and in some cases counterintuitive.

Decline index was the canopy variable most strongly correlated with soil variables in the second canonical correlation (Table 3.17). However, soil variables with the possible exception pH and Bray extractable ortho-phosphate were weak predictors of canopy decline and chemistry. Boron was the foliar variable which was the most strongly correlated with canopy decline.

There were three significant canonical correlations describing relationships between canopy and soil variables in Peterborough. However, as described above for Muskoka, loadings for soil variables as predictors of decline index were weak (Table 3.16). The first canonical correlation was largely the result of a strong positive relationship between soil phosphorus and pH and foliar phosphorus. The second canonical correlation describes a fairly strong negative relationship between soil magnesium and foliar manganese. The last describes a positive correlation between foliar boron (and to a lesser extent nitrogen and manganese) and soil calcium, magnesium, organic carbon and nitrogen.

Therefore, the results of both canonical and scatter plot analyses emphasize that there is generally a weak relationship between baseline soil and foliar variables and decline for trees within both Muskoka and Peterborough stands. The squared multiple correlation between decline index and all soil variables was 0.205 for Muskoka and 0.151 for Peterborough. While there are some groups and individual soil variables that may be considered strong predictors of foliar chemistry the measurable effect on decline index is weak.

Table 3.16 Muskoka stands 1988 intraset correlations between the canonical variates and the original foliar and soil variables

SQUARED MULTIPLE CORRELATIONS

DI	ALUT	BBUT	CAUT	MGUT	MNUT	MOUT	NAUT	NNTKUR	PPUT
0.205	0.417	0.372	0.530	0.481	0.363	0.158	0.529	0.225	0.161

CANONICAL LOADINGS (CORRELATIONS BETWEEN
DEPENDENT VARIABLES AND DEPENDENT CANONICAL FACTORS)

	1	2	3	4	5	6	7	8	9
DI	-0.141	-0.544	0.344	-0.086	0.484	0.251	0.130	0.447	-0.170
ALUT	0.677	0.198	0.326	0.183	0.442	0.333	-0.082	-0.032	0.110
BBUT	0.608	-0.453	-0.080	0.113	0.270	0.022	-0.543	0.130	0.142
CAUT	0.838	-0.003	0.101	-0.251	-0.102	0.199	-0.286	-0.085	-0.010
MGUT	0.810	0.013	0.018	-0.073	-0.157	0.169	-0.071	0.236	0.404
MNUT	-0.622	0.156	0.448	0.144	0.186	-0.102	-0.386	0.026	-0.099
MOUT	0.227	0.049	-0.469	-0.112	0.507	0.459	-0.396	0.188	0.103
NAUT	0.823	0.174	-0.129	0.278	0.194	-0.031	-0.148	0.216	-0.296
NNTKUR	0.398	-0.147	-0.322	0.528	0.279	-0.027	0.245	-0.370	0.079
PPUT	0.343	0.104	-0.041	-0.193	0.585	-0.487	0.322	-0.019	0.255

CANONICAL LOADINGS (CORRELATIONS BETWEEN
DEPENDENT VARIABLES AND DEPENDENT CANONICAL FACTORS)

	1	2	3	4	5	6	7	8	9
ALESC	0.937	-0.004	0.038	-0.161	0.217	0.086	0.170	-0.090	0.055
CAESC	-0.716	0.164	-0.236	0.512	0.249	0.079	-0.096	0.243	-0.074
KKESC	-0.166	0.224	-0.219	0.340	0.634	0.236	-0.546	-0.010	-0.059
MGESC	-0.704	0.216	-0.421	0.288	0.372	0.131	-0.132	0.138	-0.070
ORGC	0.208	0.008	-0.070	0.260	0.625	-0.032	-0.325	-0.111	-0.612
PHECA	-0.824	-0.437	0.246	0.085	-0.019	0.181	0.105	-0.130	-0.024
SNITRO	-0.014	0.122	-0.054	0.255	0.560	0.174	-0.284	-0.163	-0.683
PPO4BE	-0.398	0.468	0.364	0.131	0.491	-0.148	-0.255	0.378	0.054
SPPUT	-0.374	0.128	0.122	0.215	0.418	0.111	0.052	-0.565	-0.523

Table 3.17 Peterborough stands 1988 intraset correlations between the canonical variates and the original foliar and soil variables

SQUARED MULTIPLE CORRELATIONS

DI	ALUT	BBUT	CAUT	MGUT	MNUT	MOUT	NAUT	NNTKUR	PPUT
0.151	0.154	0.220	0.196	0.124	0.348	0.151	0.121	0.478	0.724

CANONICAL LOADINGS (CORRELATIONS BETWEEN
DEPENDENT VARIABLES AND DEPENDENT CANONICAL FACTORS)

	1	2	3	4	5
DI	0.170	0.220	0.004	0.644	-0.052
ALUT	0.298	0.342	0.119	-0.230	0.068
BBUT	-0.015	-0.425	0.527	0.054	0.121
CAUT	0.265	0.375	0.081	-0.104	-0.777
MGUT	-0.136	0.241	-0.356	0.198	-0.119
MNUT	-0.212	0.684	0.462	-0.164	0.180
MOUT	0.232	0.121	0.166	0.590	0.121
NAUT	-0.153	0.234	0.202	0.255	0.180
NNTKUR	-0.702	-0.103	0.418	0.218	-0.144
PPUT	0.943	-0.113	0.184	-0.043	0.061

	6	7	8	9
DI	-0.483	-0.316	0.337	0.185
ALUT	0.383	-0.138	0.088	0.255
BBUT	0.571	-0.220	-0.267	0.229
CAUT	0.230	0.013	-0.069	0.299
MGUT	0.325	0.467	0.385	0.361
MNUT	-0.304	0.086	0.018	0.207
MOUT	-0.083	0.630	-0.286	-0.081
NAUT	0.612	-0.458	0.146	-0.418
NNTKUR	0.181	0.223	0.368	-0.117
PPUT	-0.067	0.157	0.155	-0.069

CANONICAL LOADINGS (CORRELATIONS BETWEEN
DEPENDENT VARIABLES AND DEPENDENT CANONICAL FACTORS)

	1	2	3	4	5
ALESC	-0.465	-0.284	-0.597	0.229	0.073
CAESC	0.330	-0.075	0.790	-0.150	0.300
KKESC	0.571	0.068	0.144	0.113	-0.555
MGESC	-0.248	-0.509	0.769	0.030	0.081
ORGC	-0.195	-0.177	0.864	0.116	0.143
PHECA	0.827	0.387	0.035	-0.164	0.222
SNITRO	-0.152	0.005	0.812	0.403	0.071
PPO4BE	0.897	0.021	-0.035	0.201	-0.231
SPPUT	0.882	-0.052	0.161	0.305	-0.021

	6	7	8	9
ALESC	-0.058	0.531	-0.068	-0.007
CAESC	-0.194	0.259	0.189	0.092
KKESC	0.016	0.234	-0.029	0.522
MGESC	-0.120	0.086	-0.037	0.237
ORGC	0.005	0.361	-0.135	0.042
PHECA	-0.011	0.052	0.146	0.253
SNITRO	-0.165	0.233	0.209	0.160
PPO4BE	-0.145	0.058	-0.227	0.153
SPPUT	0.041	0.026	0.301	0.080

3.2.5 Analysis of Covariance

Analysis of covariance answers the question can the regression lines (for the categorical variable interactions (L*T*D)) be regarded as the same? And, if not, in what respects do they differ (Snedecor, 1989)?

Table 3.18 provides a summary of the slopes of relationships between decline index and soil parameters for those variables and interaction terms found to be significant. An partial example of the model for Muskoka-tapped-declining is:

$$DI_{MTD}-32.3+2.78ALESC+1.12MGESC-31.84KKESC\ldots-0.63PPUT$$

Any effects involving tapping as the primary factor, although left in the table, are not considered important. It was assumed that tapping should not greatly influence the relationship between soil chemistry and decline and that the effects due to tapping were more likely the result of physical location rather than the practice of tapping.

Exchangeable aluminum was significant in the ANCOVA and had its largest influence on decline index when examined at the level of a three way interaction between location, decline and tapping. With the exception of healthy trees at the Muskoka tapped site all of the slopes for exchangeable aluminum were positive indicating that as aluminum increased so did decline. Except in the case of the Peterborough untapped stand there was a stronger relationship between aluminum and decline index for declining trees as compared healthy trees. The slopes of the relationship between aluminum and decline were also the highest for the Peterborough stands. These results may indicate some tolerance in the Muskoka area to elevated aluminum. The results may also reflect differences in the relationship between decline index and soil aluminum concentration within two distinctly different ranges of aluminum concentrations at the two locations. The extremely high slope for the declining trees of the Peterborough tapped stand was the result of a limited number of sample trees with high decline index and low soil aluminum concentrations (see figure 3.7).

Exchangeable potassium in soils was negatively correlated with decline for all trees except for the healthy trees at the Muskoka tapped and Peterborough untapped stands. In all cases declining trees demonstrated an inverse relationship between exchangeable potassium and decline. That is for declining trees the higher the potassium concentration in soils the lower the decline index (ie. the healthier the tree). This suggests that all stands (except for soils of healthy trees at the two stands mentioned above) may be potassium limited and that declining trees are especially limited. The large slopes associated with declining trees at the Muskoka untapped stand and with all trees at the Peterborough stands suggests that responses to potassium application should be strong for these areas. However, the results of decline index responses to fertilization do not fully correspond to this analysis.

Using the findings of the DI vs soil chemistry ANCOVA as a predictor yielded mixed results. The significant terms in the ANCOVA ($p < 0.05$) are tagged with an asterisk. Less significant but still interesting terms ($0.05 < p < 0.1$) are tagged with a +. Expected responses to fertilizer treatment based on these significant terms are listed in the final column in table 3.15. For example, a positive and significant regression coefficient for ALECA suggests an acidifying soil which will be expected to respond to Ca and lime and total treatments.
The only the significant responses ($p < 0.05$) of DI to treatment were at the Peterborough declining sites (see table 3.8). Hence, it is at these two sites, that we will attempt to relate the ANCOVA with the DI-ANOVA results.

At the Peterborough tapped, declining site, in the ANCOVA, a possible response is indicated, to Ca and lime due to the significant and positive ALECA and SSO4EW coefficients (table 3.18). The negative and significant KKESC coefficient also suggests a response to K. A response to the total treatment is also expected since it has Ca, lime and K in it. From table 3.8 Ca, K, lime, N, Ph and total treatments all yield a significantly different response from the control. Hence in this case, the ANCOVA was successful as a predictor of response to field fertilization.

Applying similar logic to the Peterborough untapped declining trees we expect responses from the K, N, Ph and total treatments and indeed along with Mg all of these responses in DI were significant (see table 3.8).

Table 3.19 provides a summary of the slopes of relationships between decline index and foliar parameters for those variables and interaction terms found to be significant.

Table 3.18 Slopes from ANCOVA for DI vs soil chemistry

			INTERCEPT	REGRESSION COEFFICIENTS								SUGGESTED TREATMENTS THAT WILL PRODUCE A RESPONSE
				ALESC	MGESC	KKESC	SSO4EW	SNITRO	PPO4BE	ORGC	PPUT	
MUSKOKA	TAPPED	DECLINE	32.3	2.78	1.12	-31.84*	-0.11	3.01	0.038	2.11	-0.63	K - no significant response
		HEALTHY	10.0	-0.26	1.12	14.89	-0.11	3.01	0.038	2.11	-3.68	? - no significant responses
	UNTAPPED	DECLINE	20.7	6.22*	1.12*	-103.78+	0.69*	-3.72*	-0.31+	0.29*	21.2*	K, Lime, Ca, N, Ph - no significant responses
		HEALTHY	-1.6	5.09*	1.12*	-57.06*	0.69*	-3.72*	-0.31+	0.29*	9.29	K, Lime, Ca, N, Ph - no significant responses
PETERBOROUGH	TAPPED	DECLINE	40.1	1227*	1.12	-120.9*	0.29*	3.01	0.038	2.11	-0.63	Lime, Ca, K, Total - all had significant responses $p<0.05$
		HEALTHY	17.8	25.53	1.12+	-74.16*	0.29*	3.01	0.038	2.11	-3.68	K, Lime, Ca - no significant responses
	UNTAPPED	DECLINE	28.5	12.25	1.12	-17.9*	0.064	-3.72*	-0.31+	0.29*	21.2*	K, N, Ph, Total - all had significant responses
		HEALTHY	6.2	63.9	1.12	28.9	0.064	-3.72*	-0.31+	0.29*	9.29	N, Ph - no significant responses

Table 3.19 Slopes from ANCOVA for DI vs foliar chemistry

			INTERCEPT	REGRESSION COEFFICIENTS			
				MGUT	MNUT	MOUT	NNTKUR
MUSKOKA	TAPPED	DECLINE	8.4	0.045*	-0.00054	-0.0015*	0.88*
		HEALTHY	8.0	0.045*	-0.0021*	-0.0015*	0.88*
	UNTAPPED	DECLINE	6.9	0.045*	-0.0019	-0.0015*	0.88*
		HEALTHY	6.5	0.045*	-0.00099	-0.0015*	0.88*
PETERBOROUGH	TAPPED	DECLINE	7.5	0.008	-0.0004	-0.0015*	0.88*
		HEALTHY	7.1	0.008	0.00001	-0.0015*	0.88*
	UNTAPPED	DECLINE	6.0	0.008	0.0001	-0.0015*	0.88*
		HEALTHY	5.6	0.008	0.0007	-0.0015*	0.88*

3.2.6 Analysis of Variance on Soil and Foliar Chemistry

The planned comparisons between the control corrected difference between soil and foliar response to treatment for all trees in the study are shown in Table 3.20. The percent change (P) in a chemical parameter was calculated as follows:

$$P=(100(V_{88}-V_{89})/V_{88})-100(C_{88}-C_{89})/C_{88})$$

The results of the planned comparison in table 3.20 attempt to answer the following question. Has there been a significant increase in soil and/or foliar chemistry due to application of a treatment that contains that particular element? For example, has lime or calcium treatment caused an increase in soil and/or foliar calcium?

Excepting the calcium amendment there were significant increases in the soil and/or foliar concentrations of the element(s) added in response to all fertilizer amendments. Generally, responses were significant for only soil chemistry indicating either an overall limited uptake of nutrients or a lag in the manifestation of the uptake. Nitrogen was the only single amendment for which there was a positive response for foliage but not for soil. This may indicate that applied nitrogen was rapidly taken up and translocated to foliar tissue. The rapid uptake of applied nitrogen by foliage may have resulted in the significantly higher concentrations of nitrogen in foliage with no significant change in soil.

Table 3.20 Planned comparisons of soil and foliar chemistry

TREATMENT	TEST	P VALUE (Test- Control)
Ca	CAESC	0.649
Ca	CAUT	0.649
L	CAESC*	0.045
L	CAUT*	0.037
L	PHEW	0.157
L	MGESC	0.303
L	MGUT	0.112
K	KKESC*	0.000
K	KKUT	0.518
Mg	MGESC*	0.000
Mg	MGUT	0.434
N	SNITRO	0.379
N	NNTKUR	0.061
P	SPPUT*	0.016
P	PPUT	0.791
T	CAESC	0.347
	CAUT*	0.023
	KKESC*	0.000
	KKUT	0.608
	MGESC*	0.000
	MGUT	0.645
	SPPUT*	0.028
	PPUT	0.281
	SNITRO	0.450
	NNTKUR	0.362

* Significant at 95 percent level

The control corrected percent change between 1988 and 1989 in chemical parameters by treatment is shown graphically in figures 3.8 and 3.9. Figures 3.10 to 3.13 show the percent change for declining and healthy trees. Notice the trend toward more positive foliar response for healthy trees (figures 3.10 and 3.11). For healthy trees there are 11 responses over 5 percent vs only 7 less than -5 percent. For declining trees there are only 8 responses over 5 percent vs 16 under -5 percent. Perhaps the declining trees have a limited capacity to take in nutrients or perhaps their response is slower. It must, however, be remembered that these control corrected responses are not independent since the same control is subtracted from each chemical test. This means that the result could conceivably be dominated by a high or low control.

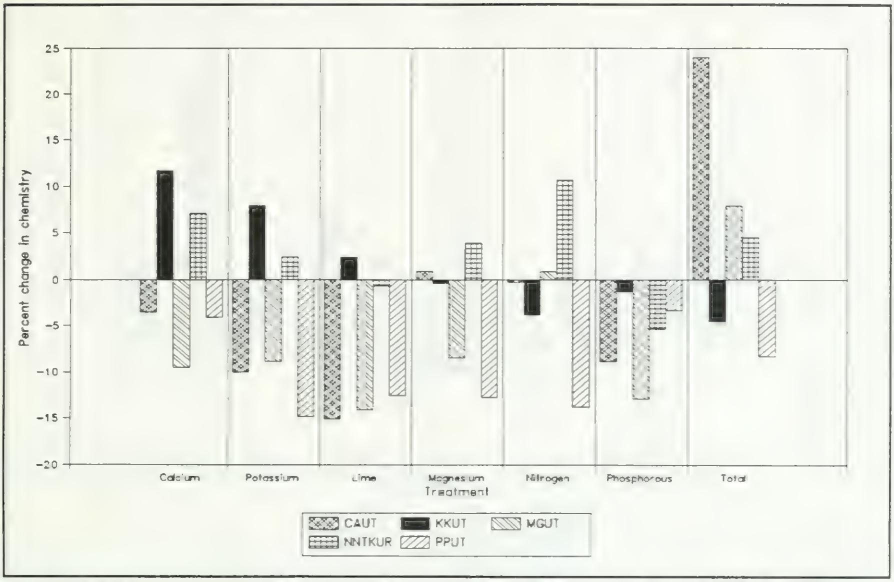


Figure 3.8 Control corrected percent change in foliar chemistry from 1988 to 1989

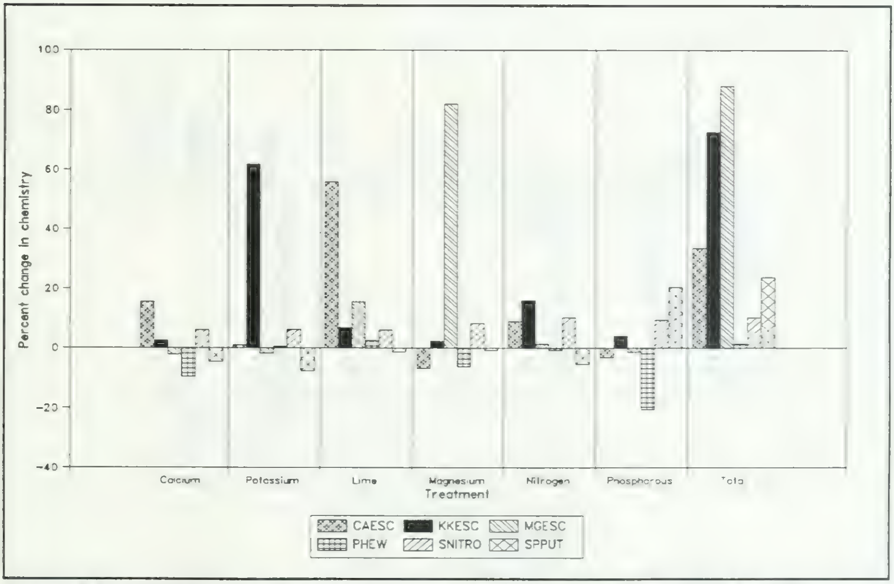


Figure 3.9 Control corrected percent change in soil chemistry from 1988 to 1989

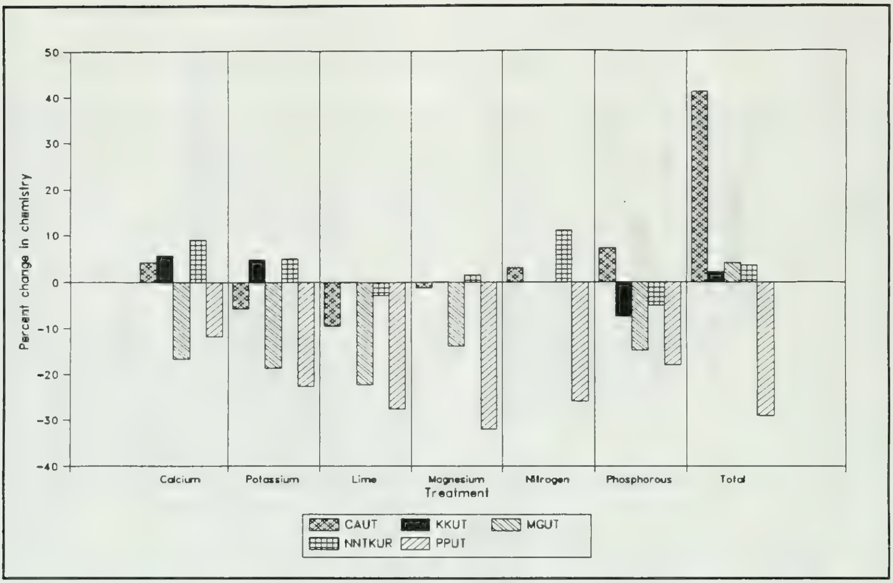


Figure 3.10 Control corrected percent change in declining foliar chemistry from 1988 to 1989

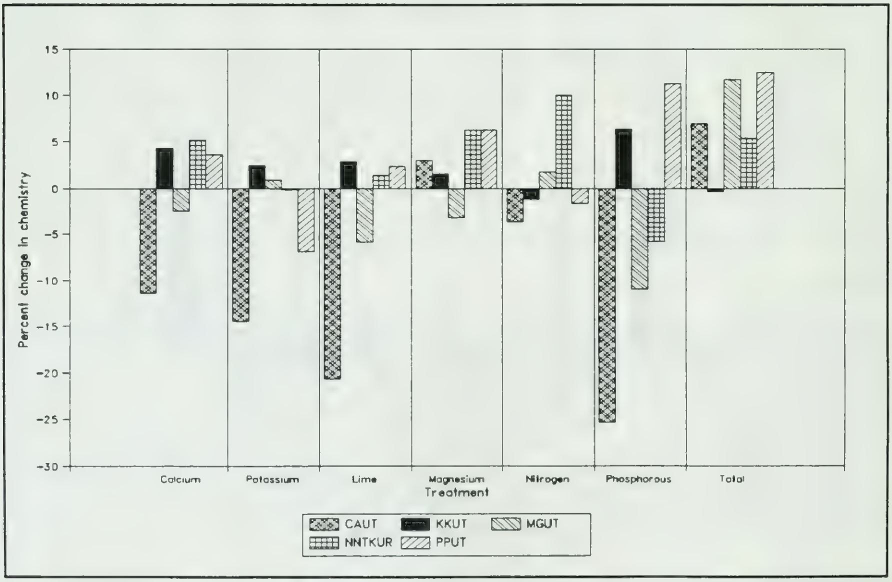


Figure 3.11 Control corrected percent change in healthy foliar chemistry from 1988 to 1989

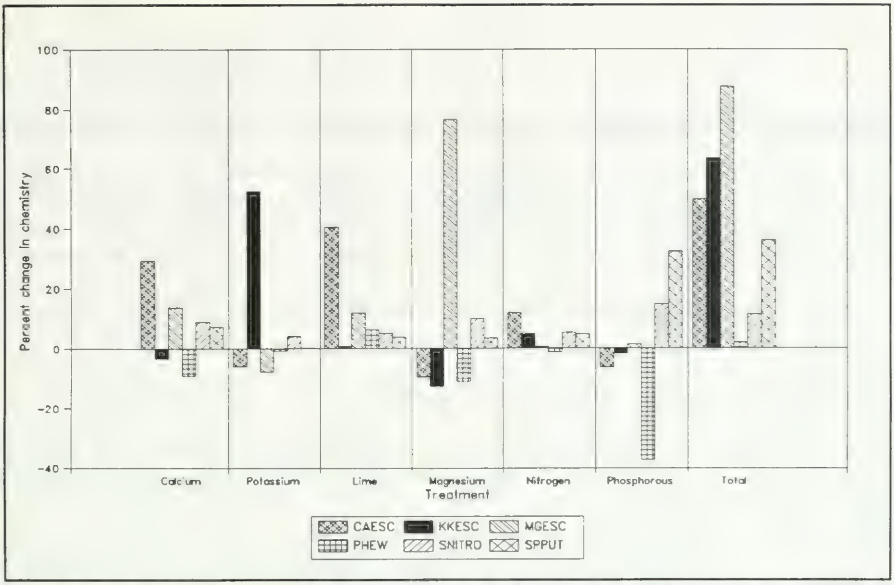


Figure 3.12 Control corrected percent change in declining soil chemistry from 1988 to 1989

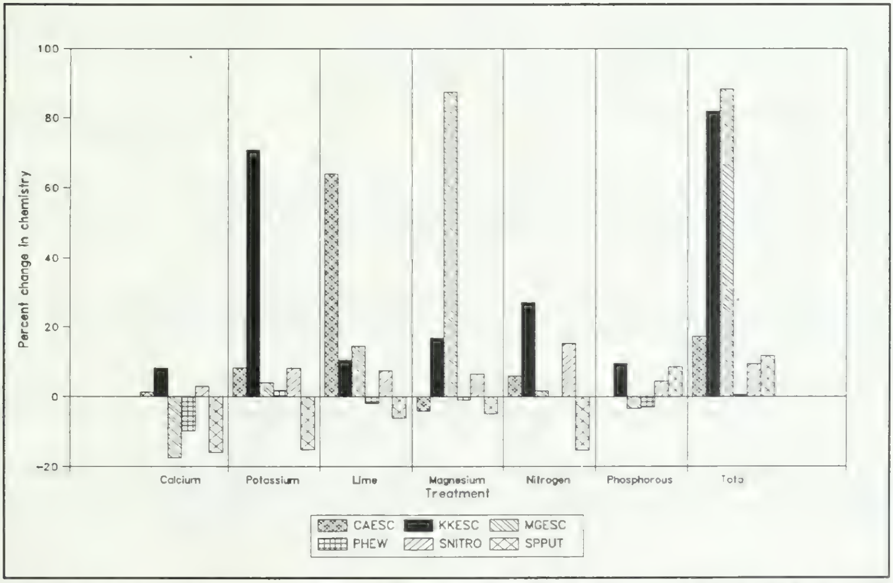


Figure 3.13 Control corrected percent change in healthy soil chemistry from 1988 to 1989

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Appendix A Soil and Foliar Chemistry

Table A1 Soil and foliar chemistry for Muskoka tapped 1988

TEST	C	CA	K	L	MG	N	Ph	T	MEAN
ALECA	4.52e+00	7.75e+00	7.70e+00	7.27e+00	3.48e+00	6.74e+00	7.10e+00	6.45e+00	6.38e+00
ALESC	8.04e-01	1.15e+00	1.57e+00	1.39e+00	5.16e-01	1.36e+00	1.14e+00	1.35e+00	1.16e+00
ALUT	3.16e+01	3.03e+01	3.33e+01	3.57e+01	3.47e+01	3.37e+01	3.28e+01	2.53e+01	3.21e+01
BBUT	8.21e+01	7.74e+01	7.97e+01	8.03e+01	8.50e+01	7.23e+01	8.19e+01	7.39e+01	7.91e+01
CAESC	7.31e+00	7.33e+00	4.91e+00	4.49e+00	8.77e+00	6.46e+00	7.05e+00	4.71e+00	6.39e+00
CAUT	1.06e+04	8.56e+03	1.02e+04	1.10e+04	1.19e+04	1.04e+04	9.01e+03	7.56e+03	9.91e+03
CLUT	1.50e-02	.	1.60e-02	1.70e-02	1.90e-02	1.70e-02	2.13e-02	.	1.80e-02
CUUT	9.34e+00	9.74e+00	1.06e+01	1.02e+01	1.13e+01	8.95e+00	9.58e+00	9.38e+00	9.87e+00
FEUT	6.86e+01	5.97e+01	6.23e+01	7.18e+01	8.24e+01	6.66e+01	7.57e+01	5.81e+01	6.81e+01
KKESC	2.44e-01	2.59e-01	2.39e-01	2.09e-01	2.47e-01	3.07e-01	2.82e-01	2.27e-01	2.52e-01
KKUT	9.85e-01	.	7.50e-01	8.70e-01	1.06e+00	8.20e-01	8.97e-01	.	9.08e-01
MGESC	9.12e-01	8.33e-01	5.96e-01	5.11e-01	9.79e-01	8.69e-01	7.12e-01	6.58e-01	7.70e-01
MGUT	1.44e+03	1.35e+03	1.53e+03	1.44e+03	1.51e+03	1.33e+03	1.29e+03	1.20e+03	1.39e+03
MNUT	5.15e+02	4.83e+02	5.72e+02	5.43e+02	4.52e+02	5.63e+02	9.29e+02	4.76e+02	5.68e+02
MOUT	3.24e-01	2.78e-01	3.56e-01	4.29e-01	3.00e-01	3.71e-01	3.56e-01	3.00e-01	3.38e-01
NAUT	1.72e+02	1.54e+02	1.45e+02	1.59e+02	1.71e+02	1.66e+02	1.53e+02	7.47e+01	1.49e+02
NIUT	1.61e+00	1.28e+00	1.38e+00	1.96e+00	1.76e+00	1.32e+00	1.48e+00	1.10e+00	1.48e+00
NNTKUR	2.19e+01	2.27e+01	2.18e+01	2.17e+01	2.28e+01	2.09e+01	2.23e+01	2.18e+01	2.20e+01
ORGC	7.65e+00	7.32e+00	7.22e+00	6.61e+00	7.36e+00	8.29e+00	8.62e+00	7.16e+00	7.55e+00
PHECA	4.27e+00	4.11e+00	3.99e+00	3.96e+00	4.44e+00	3.88e+00	3.95e+00	3.96e+00	4.07e+00
PHEW	4.80e+00	4.58e+00	4.48e+00	4.45e+00	4.91e+00	4.44e+00	4.40e+00	4.52e+00	4.57e+00
PPO4BE	1.39e+01	8.00e+00	1.39e+01	1.24e+01	2.15e+01	2.05e+01	2.40e+01	5.08e+00	1.51e+01
PPUT	1.28e+00	1.33e+00	1.37e+00	1.20e+00	1.30e+00	1.17e+00	1.40e+00	1.30e+00	1.29e+00
SNITRO	4.98e+00	4.64e+00	4.51e+00	4.05e+00	5.19e+00	5.06e+00	5.24e+00	3.82e+00	4.70e+00
SPPUT	9.12e-01	8.65e-01	9.48e-01	6.84e-01	1.51e+00	7.33e-01	6.47e-01	5.87e-01	8.56e-01
SSO4EW	2.67e+01	3.11e+01	2.14e+01	1.83e+01	2.86e+01	2.79e+01	2.61e+01	2.08e+01	2.49e+01
SSUT	2.00e-01	.	1.90e-01	2.10e-01	1.95e-01	1.85e-01	1.80e-01	.	1.93e-01
TIC	.	.	.	.	.	.	1.00e-02		1.00e-02
ZNUT	3.59e+01	2.59e+01	3.15e+01	4.39e+01	2.83e+01	3.04e+01	2.92e+01	2.24e+01	3.09e+01

Table A2 Soil and foliar chemistry for Muskoka tapped

TEST	C	CA	K	L	MG	N	Ph	T	MEAN
ALECA	2.83e+00	3.57e+00	7.24e+00	3.34e+00	1.90e+00	6.23e+00	6.10e+00	5.13e+00	4.38e+00
ALESC	8.51e-01	1.08e+00	1.85e+00	8.04e-01	4.43e-01	1.45e+00	1.23e+00	1.36e+00	1.14e+00
ALUT	3.72e+01	3.52e+01	3.85e+01	3.70e+01	3.58e+01	3.75e+01	3.83e+01	3.90e+01	3.73e+01
BBUT	6.35e+01	6.35e+01	5.63e+01	6.17e+01	6.35e+01	4.50e+01	6.05e+01	6.60e+01	6.00e+01
CAESC	6.46e+00	6.70e+00	4.32e+00	5.15e+00	6.80e+00	5.60e+00	4.34e+00	4.27e+00	5.49e+00
CAUT	1.07e+04	1.07e+04	1.08e+04	9.85e+03	1.28e+04	9.53e+03	1.08e+04	1.12e+04	1.08e+04
CDUT	1.93e-01	2.50e-01	2.83e-01	2.17e-01	2.42e-01	2.00e-01	3.17e-01	2.83e-01	2.48e-01
CLUT	4.13e-02	4.73e-02	3.30e-02	3.63e-02	2.87e-02	3.30e-02	2.80e-02	5.87e-02	3.83e-02
CUUT	6.43e+00	5.12e+00	6.05e+00	6.63e+00	5.55e+00	4.68e+00	5.38e+00	5.33e+00	5.65e+00
FEUT	6.85e+01	6.85e+01	6.60e+01	8.10e+01	7.38e+01	6.88e+01	7.18e+01	7.93e+01	7.22e+01
KKESC	2.08e-01	2.34e-01	4.34e-01	1.85e-01	1.86e-01	2.22e-01	1.91e-01	3.38e-01	2.52e-01
KKUT	8.58e-01	6.73e-01	7.70e-01	7.12e-01	7.33e-01	6.68e-01	5.62e-01	8.73e-01	7.31e-01
MGESC	8.29e-01	7.78e-01	5.71e-01	4.92e-01	1.68e+00	6.41e-01	4.88e-01	9.93e-01	8.23e-01
MGUT	1.36e+03	1.48e+03	1.63e+03	1.37e+03	1.55e+03	1.37e+03	1.33e+03	1.60e+03	1.46e+03
MNUT	4.78e+02	5.68e+02	5.58e+02	4.72e+02	4.45e+02	4.62e+02	1.01e+03	6.62e+02	5.81e+02
MOUT	3.83e-01	3.83e-01	3.83e-01	3.67e-01	2.50e-01	3.17e-01	2.83e-01	4.67e-01	3.54e-01
NAUT	7.23e+01	6.07e+01	6.07e+01	7.47e+01	5.67e+01	6.35e+01	5.78e+01	6.50e+01	6.39e+01
NIUT	2.50e+00	1.35e+00	2.05e+00	2.00e+00	2.58e+00	1.33e+00	1.78e+00	1.17e+00	1.85e+00
NNTKUR	2.02e+01	2.05e+01	2.17e+01	1.90e+01	2.18e+01	2.13e+01	2.00e+01	2.23e+01	2.09e+01
ORGC	5.91e+00	7.16e+00	6.86e+00	5.83e+00	7.36e+00	6.94e+00	6.16e+00	6.67e+00	6.63e+00
PBUT	8.17e+00	4.65e+00	6.12e+00	5.07e+00	5.67e+00	4.20e+00	6.33e+00	8.72e+00	6.11e+00
PHECA	4.48e+00	4.27e+00	4.09e+00	4.49e+00	4.57e+00	4.14e+00	4.13e+00	4.18e+00	4.29e+00
PHEW	5.05e+00	4.88e+00	4.73e+00	5.09e+00	5.16e+00	4.80e+00	4.81e+00	4.80e+00	4.92e+00
PPO4BE	1.23e+01	1.66e+01	1.38e+01	1.75e+01	3.16e+01	2.04e+01	6.24e+01	6.13e+01	2.90e+01
PPUT	1.32e+00	1.47e+00	1.37e+00	1.32e+00	1.48e+00	1.33e+00	1.50e+00	1.52e+00	1.41e+00
SNITRO	4.44e+00	4.84e+00	4.57e+00	4.13e+00	6.11e+00	4.53e+00	4.20e+00	4.63e+00	4.69e+00
SPPUT	9.11e-01	9.64e-01	8.76e-01	7.91e-01	1.80e+00	7.63e-01	9.53e-01	9.73e-01	1.01e+00
SSO4EW	1.70e+01	4.97e+01	6.01e+01	1.67e+01	3.34e+01	1.96e+01	1.80e+01	1.08e+02	4.13e+01
SSUT	1.12e-01	1.29e-01	1.11e-01	1.04e-01	1.20e-01	9.40e-02	1.01e-01	1.25e-01	1.12e-01
TIC	1.00e-02	1.00e-02	5.00e-03	3.00e-02	.	.	.	.	1.20e-02
ZNUT	3.27e+01	3.20e+01	3.58e+01	3.52e+01	3.10e+01	2.72e+01	3.65e+01	3.38e+01	3.30e+01

Table A3 Soil and foliar chemistry for Muskoka untapped for 1988

TEST	C	CA	K	L	MG	N	Ph	T	MEAN
ALECA	1.97e+01	1.76e+01	1.89e+01	2.23e+01	2.29e+01	1.92e+01	1.86e+01	1.85e+01	1.97e+01
ALESC	2.34e+00	2.52e+00	2.16e+00	2.36e+00	2.31e+00	2.41e+00	2.40e+00	2.61e+00	2.38e+00
ALUT	2.21e+01	2.45e+01	2.19e+01	2.41e+01	2.23e+01	2.34e+01	2.35e+01	2.33e+01	2.31e+01
BBUT	5.07e+01	5.47e+01	4.99e+01	4.52e+01	5.28e+01	4.41e+01	6.44e+01	5.14e+01	5.18e+01
CAESC	2.74e+00	2.09e+00	2.36e+00	1.34e+00	3.05e+00	1.73e+00	2.67e+00	2.10e+00	2.25e+00
CAUT	5.25e+03	6.36e+03	6.74e+03	6.90e+03	6.07e+03	5.68e+03	6.59e+03	5.54e+03	6.13e+03
CLUT	1.83e-03	1.83e-03	2.83e-03	1.60e-03	1.50e-03	2.40e-03	2.67e-03	1.00e-03	1.96e-03
CUUT	7.76e+00	7.26e+00	7.61e+00	6.73e+00	7.07e+00	7.33e+00	7.63e+00	6.47e+00	7.24e+00
FEUT	5.19e+01	5.88e+01	4.88e+01	5.27e+01	4.70e+01	4.66e+01	5.37e+01	4.85e+01	5.10e+01
KKESC	2.13e-01	1.80e-01	2.05e-01	1.88e-01	2.37e-01	1.71e-01	2.17e-01	1.89e-01	2.00e-01
MGESC	3.41e-01	2.74e-01	2.74e-01	1.92e-01	3.68e-01	2.58e-01	3.04e-01	2.68e-01	2.83e-01
MGUT	8.29e+02	1.07e+03	9.99e+02	9.63e+02	1.01e+03	8.39e+02	9.86e+02	8.33e+02	9.41e+02
MNUT	6.56e+02	7.10e+02	8.54e+02	1.08e+03	7.52e+02	7.82e+02	1.00e+03	1.17e+03	8.73e+02
MOUT	1.94e-01	1.61e-01	2.11e-01	2.06e-01	3.06e-01	2.61e-01	2.50e-01	2.50e-01	2.30e-01
NAUT	7.77e+01	5.20e+01	5.32e+01	5.74e+01	6.11e+01	6.49e+01	5.79e+01	5.17e+01	5.95e+01
NIUT	1.08e+00	1.08e+00	1.08e+00	1.12e+00	1.01e+00	1.14e+00	1.17e+00	7.64e-01	1.05e+00
NNTKUR	1.99e+01	1.93e+01	2.00e+01	1.94e+01	2.10e+01	1.79e+01	2.09e+01	2.24e+01	2.01e+01
ORGC	8.46e+00	7.29e+00	9.88e+00	6.46e+00	9.62e+00	7.01e+00	1.10e+01	7.77e+00	8.47e+00
PHECA	3.73e+00	3.73e+00	3.87e+00	3.83e+00	3.86e+00	3.57e+00	3.62e+00	3.70e+00	3.74e+00
PHEW	4.19e+00	4.21e+00	4.27e+00	4.21e+00	4.29e+00	3.98e+00	4.00e+00	4.13e+00	4.16e+00
PPO4BE	6.73e+00	8.61e+00	6.49e+00	1.12e+01	6.33e+00	9.03e+00	6.03e+00	9.31e+00	7.86e+00
PPUT	1.11e+00	1.00e+00	1.19e+00	1.21e+00	1.24e+00	1.13e+00	1.23e+00	1.24e+00	1.17e+00
SNITRO	4.48e+00	4.29e+00	5.33e+00	3.52e+00	5.32e+00	3.37e+00	5.79e+00	4.18e+00	4.55e+00
SPPUT	6.29e-01	6.51e-01	9.97e-01	6.63e-01	8.19e-01	5.33e-01	8.98e-01	6.43e-01	7.37e-01
SSO4EW	2.87e+01	1.89e+01	2.49e+01	2.70e+01	3.03e+01	2.33e+01	2.46e+01	2.32e+01	2.49e+01
SSUT	1.09e-01	1.07e-01	1.34e-01	1.24e-01	1.07e-01	1.21e-01	1.21e-01	1.19e-01	1.17e-01
ZNUT	2.00e+01	2.91e+01	2.27e+01	2.39e+01	2.33e+01	2.12e+01	2.05e+01	2.26e+01	2.29e+01

Table A4 Soil and foliar chemistry for Muskoka untapped for 1989

TEST	C	CA	K	L	MG	N	Ph	T	MEAN
ALECA	1.50e+01	1.54e+01	1.41e+01	1.27e+01	1.43e+01	2.57e+01	1.70e+01	1.66e+01	1.67e+01
ALESC	2.16e+00	2.12e+00	1.94e+00	1.70e+00	2.25e+00	2.68e+00	2.12e+00	2.25e+00	2.15e+00
ALUT	3.45e+01	3.55e+01	3.30e+01	3.60e+01	3.60e+01	3.95e+01	3.82e+01	3.93e+01	3.65e+01
BBUT	6.95e+01	7.35e+01	5.98e+01	6.12e+01	7.17e+01	6.03e+01	7.92e+01	6.53e+01	6.76e+01
CAESC	1.50e+00	2.32e+00	1.76e+00	2.63e+00	1.79e+00	1.07e+00	1.52e+00	3.54e+00	2.02e+00
CAUT	7.20e+03	7.17e+03	7.22e+03	7.58e+03	8.87e+03	7.38e+03	7.62e+03	9.80e+03	7.85e+03
CDUT	1.58e-01	1.65e-01	1.83e-01	2.50e-01	2.58e-01	2.97e-01	2.38e-01	3.73e-01	2.40e-01
CLUT	4.70e-02	3.70e-02	2.93e-02	2.77e-02	4.27e-02	4.70e-02	4.40e-02	4.23e-02	3.96e-02
CUUT	6.72e+00	7.10e+00	6.77e+00	6.15e+00	6.38e+00	5.53e+00	6.67e+00	6.00e+00	6.41e+00
FEUT	5.87e+01	7.15e+01	6.23e+01	6.23e+01	6.42e+01	7.52e+01	6.35e+01	9.60e+01	6.92e+01
KKESC	1.88e-01	1.68e-01	2.23e-01	1.81e-01	1.82e-01	1.59e-01	2.38e-01	2.04e-01	1.94e-01
KKUT	7.88e-01	9.43e-01	8.93e-01	7.67e-01	7.92e-01	7.77e-01	1.01e+00	8.20e-01	8.49e-01
MGESC	2.27e-01	1.85e-01	2.24e-01	2.32e-01	5.36e-01	1.81e-01	2.62e-01	4.46e-01	2.88e-01
MGUT	1.05e+03	1.11e+03	1.13e+03	1.11e+03	1.30e+03	1.31e+03	1.17e+03	1.34e+03	1.19e+03
MNUT	6.85e+02	7.77e+02	7.15e+02	1.01e+03	8.97e+02	1.16e+03	1.01e+03	1.58e+03	9.79e+02
MOUT	2.83e-01	3.00e-01	2.50e-01	2.67e-01	2.83e-01	2.17e-01	3.00e-01	2.67e-01	2.71e-01
NAUT	9.35e+01	1.12e+02	8.85e+01	9.05e+01	1.05e+02	8.95e+01	6.52e+01	8.12e+01	9.07e+01
NIUT	1.63e+00	2.15e+00	1.92e+00	2.07e+00	1.87e+00	1.63e+00	2.25e+00	1.70e+00	1.90e+00
NNTKUR	2.03e+01	2.20e+01	2.12e+01	2.05e+01	2.25e+01	2.43e+01	2.17e+01	2.42e+01	2.21e+01
ORGC	6.66e+00	6.42e+00	6.90e+00	6.39e+00	6.56e+00	5.77e+00	1.11e+01	6.05e+00	7.00e+00
PBUT	5.33e+00	9.93e+00	4.10e+00	5.20e+00	5.47e+00	4.80e+00	2.68e+00	4.92e+00	5.30e+00
PHECA	4.05e+00	4.14e+00	4.09e+00	4.15e+00	3.97e+00	3.85e+00	4.08e+00	4.24e+00	4.07e+00
PHEW	4.67e+00	4.72e+00	4.74e+00	4.69e+00	4.66e+00	4.39e+00	4.74e+00	4.84e+00	4.68e+00
PPO4BE	1.32e+01	8.09e+00	1.19e+01	1.59e+01	1.16e+01	1.28e+01	2.26e+01	2.80e+01	1.56e+01
PPUT	1.28e+00	1.27e+00	1.15e+00	1.16e+00	1.27e+00	1.32e+00	1.40e+00	1.53e+00	1.30e+00
SNITRO	4.05e+00	3.73e+00	4.55e+00	3.99e+00	3.94e+00	3.43e+00	7.66e+00	3.31e+00	4.35e+00
SPPUT	7.33e-01	6.40e-01	8.44e-01	7.47e-01	7.02e-01	6.34e-01	1.36e+00	6.86e-01	7.98e-01
SSO4EW	2.16e+01	4.48e+01	3.20e+01	2.48e+01	3.07e+01	1.74e+01	3.14e+01	6.52e+01	3.37e+01
SSUT	1.22e-01	2.65e-01	1.50e-01	1.28e-01	1.41e-01	1.37e-01	1.33e-01	1.40e-01	1.52e-01
TIC	5.00e-03	1.00e-02	1.50e-02	3.00e-02	8.00e-03	.	5.71e-03	6.20e-01	4.24e-02
ZNUT	2.83e+01	3.58e+01	3.42e+01	3.45e+01	3.20e+01	2.92e+01	3.52e+01	3.63e+01	3.32e+01

Table A5 Soil and foliar chemistry for Peterborough tapped for 1988

TEST	C	CA	K	L	MG	N	Ph	T	MEAN
ALECA	3.93e-01	2.22e-01	2.56e-01	5.67e-01	1.83e-01	2.83e-01	2.67e-01	1.28e-01	2.85e-01
ALESC	1.43e-02	2.03e-02	9.72e-03	1.53e-02	1.78e-02	1.97e-02	1.33e-02	1.14e-02	1.52e-02
ALUT	4.05e+01	3.66e+01	3.54e+01	4.21e+01	3.48e+01	3.65e+01	4.09e+01	3.66e+01	3.79e+0
BBUT	6.62e+01	6.82e+01	5.70e+01	5.72e+01	7.21e+01	6.22e+01	7.16e+01	5.55e+01	6.38e+0
CAESC	1.73e+01	1.78e+01	2.08e+01	1.50e+01	1.93e+01	1.83e+01	1.51e+01	1.79e+01	1.77e+0
CAUT	1.55e+04	1.60e+04	1.56e+04	1.60e+04	1.75e+04	1.53e+04	1.63e+04	1.53e+04	1.60e+0
CLUT	6.25e-03	9.00e-03	1.18e-02	1.87e-02	1.48e-02	1.38e-02	1.10e-02	1.47e-02	1.27e-02
CUUT	7.49e+00	7.24e+00	7.57e+00	7.78e+00	8.06e+00	6.51e+00	7.13e+00	7.79e+00	7.45e+0
FEUT	6.68e+01	6.23e+01	7.43e+01	6.97e+01	6.05e+01	6.31e+01	6.42e+01	6.11e+01	6.52e+0
KKESC	4.62e-01	2.27e-01	2.54e-01	2.63e-01	2.05e-01	2.46e-01	1.93e-01	1.99e-01	2.52e-01
KKUT	8.20e-01	8.47e-01	8.48e-01	8.93e-01	8.26e-01	8.88e-01	8.25e-01	9.82e-01	8.69e-01
MGESC	7.29e-01	5.12e-01	7.40e-01	5.94e-01	6.62e-01	6.50e-01	5.74e-01	5.81e-01	6.28e-01
MGUT	1.72e+03	1.81e+03	1.78e+03	1.96e+03	1.86e+03	1.71e+03	1.71e+03	1.83e+03	1.80e+0
MNUT	1.36e+02	1.07e+02	1.17e+02	1.29e+02	1.24e+02	1.14e+02	1.19e+02	1.56e+02	1.25e+0
MOUT	4.47e-01	3.67e-01	4.00e-01	4.28e-01	3.37e-01	4.56e-01	3.39e-01	5.11e-01	4.09e-01
NAUT	9.16e+01	1.04e+02	6.28e+01	8.42e+01	1.23e+02	7.93e+01	1.51e+02	9.42e+01	9.92e+0
NIUT	3.60e-01	2.64e-01	2.89e-01	3.36e-01	2.50e-01	2.50e-01	2.64e-01	4.14e-01	3.02e-01
NNTKUR	1.55e+01	1.57e+01	1.47e+01	1.58e+01	1.66e+01	1.64e+01	1.72e+01	1.57e+01	1.60e+0
ORGC	4.36e+00	3.74e+00	4.86e+00	3.53e+00	4.01e+00	4.09e+00	3.62e+00	4.01e+00	4.02e+0
PHECA	6.29e+00	6.56e+00	6.30e+00	6.11e+00	6.33e+00	6.38e+00	5.94e+00	6.19e+00	6.26e+0
PHEW	6.85e+00	7.07e+00	6.79e+00	6.65e+00	6.89e+00	6.95e+00	6.54e+00	6.75e+00	6.81e+0
PPO4BE	1.10e+02	7.69e+01	7.63e+01	8.45e+01	7.24e+01	8.15e+01	6.35e+01	5.36e+01	7.66e+0
PPUT	2.39e+00	2.58e+00	2.42e+00	2.52e+00	2.48e+00	2.32e+00	2.17e+00	2.37e+00	2.41e+0
SNITRO	3.04e+00	2.51e+00	2.86e+00	2.52e+00	2.64e+00	3.06e+00	2.23e+00	2.53e+00	2.67e+0
SPPUT	1.13e+00	9.28e-01	9.47e-01	8.88e-01	9.55e-01	1.02e+00	8.59e-01	8.60e-01	9.45e-01
SSO4EW	8.16e+01	2.72e+01	2.32e+01	4.28e+01	1.86e+01	4.02e+01	2.31e+01	2.04e+01	3.36e+0
SSUT	1.95e-01	1.98e-01	1.67e-01	1.93e-01	1.74e-01	1.92e-01	1.98e-01	2.22e-01	1.93e-01
TIC	2.00e-02	5.44e-02	5.67e-02	3.18e-02	6.72e-02	1.54e-01	1.64e-02	5.06e-02	5.74e-02
ZNUT	1.29e+01	1.11e+01	9.72e+00	1.27e+01	1.21e+01	1.06e+01	1.04e+01	1.34e+01	1.16e+0

Table A6 Soil and foliar chemistry for Peterborough tapped for 1989

TEST	C	CA	K	L	MG	N	Ph	T	MEAN
ALECA	2.08e-01	1.12e-01	1.86e-01	1.27e-01	1.28e-01	1.28e-01	1.81e-01	1.31e-01	1.48e-01
ALESC	1.37e-02	5.00e-03	8.82e-03	8.53e-03	5.00e-03	6.67e-03	1.97e-02	5.88e-03	8.93e-03
ALUT	3.10e+01	2.97e+01	2.68e+01	3.10e+01	2.93e+01	3.00e+01	3.08e+01	2.87e+01	2.96e+01
BBUT	5.64e+01	6.90e+01	6.73e+01	7.07e+01	6.73e+01	6.55e+01	7.43e+01	5.78e+01	6.63e+01
CAESC	1.49e+01	1.65e+01	1.64e+01	1.38e+01	1.38e+01	1.58e+01	1.31e+01	1.54e+01	1.50e+01
CAUT	1.86e+04	1.58e+04	1.52e+04	1.63e+04	1.80e+04	1.63e+04	1.58e+04	1.73e+04	1.66e+04
CDUT	7.60e-02	8.33e-02	5.00e-02	1.18e-01	8.33e-02	7.17e-02	7.67e-02	1.25e-01	8.57e-02
CLUT	2.32e-02	3.37e-02	3.40e-02	3.63e-02	3.67e-02	3.87e-02	4.13e-02	3.20e-02	3.47e-02
CUUT	5.00e+00	5.28e+00	4.55e+00	5.88e+00	5.43e+00	5.25e+00	5.65e+00	4.83e+00	5.24e+00
FEUT	5.76e+01	3.80e+01	3.38e+01	3.92e+01	3.43e+01	4.07e+01	4.03e+01	4.15e+01	4.03e+01
KKESC	1.79e-01	2.01e-01	3.45e-01	1.81e-01	1.91e-01	1.79e-01	1.64e-01	3.55e-01	2.25e-01
KKUT	7.80e-01	8.72e-01	8.53e-01	8.78e-01	8.18e-01	7.95e-01	9.02e-01	8.52e-01	8.45e-01
MGESC	5.75e-01	5.03e-01	6.28e-01	5.51e-01	1.08e+00	5.50e-01	4.88e-01	1.14e+00	6.92e-01
MGUT	2.14e+03	1.90e+03	1.72e+03	1.98e+03	1.88e+03	1.68e+03	1.75e+03	1.82e+03	1.85e+03
MNUT	1.77e+02	1.22e+02	1.15e+02	1.21e+02	1.08e+02	1.19e+02	1.29e+02	1.54e+02	1.30e+02
MOUT	5.40e-01	6.67e-01	4.50e-01	6.83e-01	5.83e-01	5.17e-01	6.17e-01	5.17e-01	5.72e-01
NAUT	7.28e+01	8.30e+01	7.82e+01	1.04e+02	1.00e+02	6.02e+01	1.10e+02	9.15e+01	8.77e+01
NIUT	4.30e-01	2.50e-01	3.08e-01	3.42e-01	5.08e-01	5.33e-01	5.42e-01	3.67e-01	4.10e-01
NNTKUR	1.60e+01	1.65e+01	1.48e+01	1.58e+01	1.63e+01	1.60e+01	1.58e+01	1.57e+01	1.59e+01
ORGC	3.95e+00	4.21e+00	4.24e+00	3.19e+00	3.64e+00	4.24e+00	3.31e+00	3.88e+00	3.84e+00
PBUT	4.14e+00	5.77e+00	7.27e+00	5.67e+00	6.68e+00	1.30e+01	6.60e+00	6.93e+00	7.07e+00
PHECA	6.34e+00	6.73e+00	6.54e+00	6.81e+00	6.38e+00	6.45e+00	6.32e+00	6.44e+00	6.51e+00
PHEW	6.93e+00	7.36e+00	7.07e+00	7.47e+00	6.98e+00	7.00e+00	6.99e+00	6.94e+00	7.09e+00
PPO4BE	9.56e+01	7.60e+01	8.44e+01	7.56e+01	8.18e+01	8.46e+01	1.24e+02	1.14e+02	9.14e+01
PPUT	4.08e+00	4.20e+00	3.63e+00	3.93e+00	3.50e+00	3.02e+00	3.80e+00	3.27e+00	3.67e+00
SNITRO	2.77e+00	2.87e+00	3.23e+00	2.54e+00	2.72e+00	3.02e+00	2.09e+00	2.69e+00	2.75e+00
SPPUT	1.04e+00	9.88e-01	1.13e+00	9.12e-01	9.99e-01	9.46e-01	9.22e-01	1.01e+00	9.86e-01
SSO4EW	1.04e+01	1.46e+01	5.74e+01	1.31e+01	1.56e+01	2.58e+01	1.00e+01	1.11e+02	3.24e+01
SSUT	1.62e-01	1.73e-01	1.37e-01	1.55e-01	1.55e-01	1.15e-01	1.33e-01	1.72e-01	1.50e-01
TIC	1.30e-02	8.94e-02	7.69e-02	3.65e-02	4.44e-02	7.97e-02	5.73e-02	2.50e-02	5.34e-02
ZNUT	2.00e+01	1.23e+01	1.10e+01	1.40e+01	1.25e+01	1.38e+01	1.25e+01	1.30e+01	1.35e+01

Table A7 Soil and foliar chemistry for Peterborough untapped for 1988

TEST	C	CA	K	L	MG	N	Ph	T	MEAN
ALECA	8.06e-01	1.09e+00	4.83e-01	1.55e+00	8.94e-01	9.94e-01	6.28e-01	1.13e+00	9.34e-01
ALESC	4.78e-02	5.14e-02	1.61e-02	5.67e-02	3.08e-02	5.92e-02	2.92e-02	7.00e-02	4.49e-02
ALUT	3.70e+01	3.16e+01	3.21e+01	3.12e+01	3.58e+01	3.46e+01	3.13e+01	3.77e+01	3.39e+01
BBUT	6.54e+01	6.07e+01	7.94e+01	6.41e+01	6.13e+01	6.24e+01	5.68e+01	6.62e+01	6.45e+01
CAESC	1.23e+01	1.43e+01	1.73e+01	1.22e+01	1.85e+01	1.45e+01	2.10e+01	1.36e+01	1.55e+01
CAUT	1.64e+04	1.51e+04	1.62e+04	1.40e+04	1.56e+04	1.60e+04	1.55e+04	1.43e+04	1.54e+04
CUUT	8.11e+00	6.96e+00	7.39e+00	7.31e+00	7.79e+00	7.93e+00	6.74e+00	7.44e+00	7.45e+00
FEUT	6.57e+01	5.97e+01	6.56e+01	6.34e+01	6.93e+01	7.35e+01	5.84e+01	7.56e+01	6.63e+01
KKESC	1.31e-01	1.25e-01	1.66e-01	1.21e-01	1.37e-01	1.01e-01	1.63e-01	9.72e-02	1.30e-01
MGESC	6.53e-01	7.91e-01	8.11e-01	6.49e-01	9.79e-01	8.36e-01	8.06e-01	7.68e-01	7.90e-01
MGUT	2.01e+03	2.11e+03	1.85e+03	1.62e+03	2.02e+03	2.02e+03	1.96e+03	1.84e+03	1.93e+03
MNUT	1.97e+02	1.14e+02	1.47e+02	1.06e+02	2.49e+02	3.20e+02	8.49e+01	1.56e+02	1.71e+02
MOUT	3.44e-01	3.78e-01	3.50e-01	3.33e-01	4.06e-01	3.83e-01	3.26e-01	4.06e-01	3.66e-01
NAUT	1.35e+02	9.41e+01	1.37e+02	1.24e+02	1.03e+02	1.05e+02	8.86e+01	1.40e+02	1.16e+02
NIUT	4.67e-01	6.19e-01	3.08e-01	4.58e-01	6.67e-01	8.03e-01	2.76e-01	8.11e-01	5.49e-01
NNTKUR	2.03e+01	1.97e+01	1.98e+01	2.14e+01	1.76e+01	2.30e+01	1.91e+01	2.33e+01	2.05e+01
ORGC	3.83e+00	4.70e+00	4.35e+00	3.99e+00	5.26e+00	5.13e+00	5.42e+00	4.89e+00	4.71e+00
PHECA	5.23e+00	5.21e+00	5.76e+00	5.12e+00	5.22e+00	4.96e+00	5.77e+00	5.07e+00	5.30e+00
PHEW	5.68e+00	5.56e+00	6.14e+00	5.50e+00	5.64e+00	5.44e+00	6.23e+00	5.55e+00	5.72e+00
PPO4BE	2.46e+01	1.36e+01	1.86e+01	9.37e+00	1.55e+01	1.79e+01	1.43e+01	1.55e+01	1.63e+01
PPUT	1.46e+00	1.19e+00	1.30e+00	1.27e+00	1.14e+00	1.30e+00	1.41e+00	1.31e+00	1.30e+00
SNITRO	2.55e+00	2.88e+00	3.07e+00	2.70e+00	3.14e+00	2.88e+00	3.88e+00	2.87e+00	3.00e+00
SPPUT	6.18e-01	5.16e-01	6.88e-01	4.63e-01	5.45e-01	3.83e-01	7.28e-01	4.37e-01	5.50e-01
SSO4EW	3.78e+01	3.15e+01	6.04e+01	2.49e+01	4.01e+01	2.10e+01	3.22e+01	2.10e+01	3.35e+01
TIC	1.23e-02	1.42e-02	3.94e-02	1.71e-02	1.36e-02	8.33e-03	2.80e-02	1.05e-02	2.00e-02
ZNUT	1.46e+01	1.42e+01	1.31e+01	1.42e+01	1.56e+01	1.60e+01	1.19e+01	1.73e+01	1.46e+01

Table A8 Soil and foliar chemistry for Peterborough untapped for 1989

TEST	C	CA	K	L	MG	N	Ph	T	MEAN
ALECA	3.55e-01	5.33e-01	1.36e-01	9.40e-01	1.21e+00	4.80e-01	1.25e-01	5.55e-01	5.53e-01
ALESC	1.89e-02	5.07e-02	1.08e-02	1.61e-02	7.22e-02	3.03e-02	1.08e-02	2.36e-02	2.87e-02
ALUT	2.85e+01	2.77e+01	2.78e+01	2.73e+01	2.55e+01	3.10e+01	2.65e+01	2.87e+01	2.79e+01
BBUT	7.18e+01	6.92e+01	6.63e+01	6.17e+01	6.45e+01	6.97e+01	5.33e+01	7.87e+01	6.69e+01
CAESC	1.36e+01	1.89e+01	1.85e+01	1.57e+01	1.79e+01	1.85e+01	2.36e+01	1.60e+01	1.78e+01
CAUT	1.73e+04	1.73e+04	1.83e+04	1.45e+04	1.65e+04	1.82e+04	1.52e+04	1.72e+04	1.68e+04
CDUT	1.57e-01	1.63e-01	9.67e-02	1.07e-01	1.58e-01	2.00e-01	8.00e-02	1.30e-01	1.36e-01
CLUT	2.00e-02	2.53e-02	1.39e-02	2.11e-02	1.14e-02	2.95e-02	2.43e-02	2.30e-02	2.08e-02
CUUT	5.98e+00	4.90e+00	5.93e+00	5.30e+00	6.10e+00	4.97e+00	4.90e+00	4.42e+00	5.31e+00
FEUT	4.72e+01	4.68e+01	4.62e+01	4.62e+01	5.43e+01	6.13e+01	4.10e+01	5.43e+01	4.97e+01
KKESC	1.33e-01	1.09e-01	2.38e-01	1.38e-01	1.29e-01	1.53e-01	1.67e-01	1.86e-01	1.58e-01
KKUT	6.52e-01	5.38e-01	6.72e-01	6.92e-01	6.12e-01	5.20e-01	5.94e-01	6.15e-01	6.13e-01
MGESC	8.20e-01	9.38e-01	8.91e-01	8.21e-01	1.82e+00	1.10e+00	1.02e+00	1.39e+00	1.10e+00
MGUT	1.97e+03	2.08e+03	2.00e+03	1.52e+03	1.95e+03	2.03e+03	1.63e+03	1.72e+03	1.86e+03
MNUT	1.58e+02	1.11e+02	1.30e+02	1.05e+02	2.02e+02	2.17e+02	6.22e+01	1.27e+02	1.39e+02
MOUT	5.00e-01	5.00e-01	4.50e-01	4.67e-01	4.17e-01	4.17e-01	5.00e-01	4.50e-01	4.63e-01
NAUT	4.83e+01	5.23e+01	4.05e+01	5.15e+01	3.93e+01	7.47e+01	5.63e+01	6.28e+01	5.32e+01
NIUT	7.00e-01	6.42e-01	6.17e-01	5.92e-01	4.58e-01	7.67e-01	6.83e-01	5.25e-01	6.23e-01
NNTKUR	1.67e+01	1.98e+01	1.67e+01	1.78e+01	1.68e+01	1.95e+01	1.40e+01	2.03e+01	1.77e+01
ORGC	3.01e+00	4.90e+00	3.73e+00	4.16e+00	4.81e+00	6.60e+00	5.21e+00	4.12e+00	4.56e+00
PBUT	7.15e+00	6.32e+00	4.12e+00	3.37e+00	5.82e+00	5.00e+00	2.25e+00	1.05e+01	5.56e+00
PHECA	5.42e+00	5.22e+00	6.06e+00	5.81e+00	5.53e+00	5.11e+00	5.99e+00	5.31e+00	5.57e+00
PHEW	5.94e+00	5.73e+00	6.63e+00	6.35e+00	6.08e+00	5.68e+00	6.53e+00	5.88e+00	6.11e+00
PPO4BE	3.32e+01	2.15e+01	2.46e+01	1.70e+01	2.07e+01	2.20e+01	7.20e+01	6.01e+01	3.42e+01
PPUT	1.43e+00	1.22e+00	1.33e+00	1.33e+00	1.25e+00	1.23e+00	1.45e+00	1.38e+00	1.33e+00
SNITRO	2.30e+00	3.13e+00	2.81e+00	2.58e+00	3.05e+00	3.35e+00	3.65e+00	2.57e+00	2.93e+00
SPPUT	6.16e-01	5.44e-01	6.79e-01	4.91e-01	6.09e-01	4.03e-01	7.54e-01	5.02e-01	5.75e-01
SSO4EW	2.37e+01	3.24e+01	1.01e+02	1.81e+01	4.21e+01	1.96e+01	1.61e+01	6.18e+01	4.01e+01
SSUT	1.59e-01	1.51e-01	1.87e-01	1.55e-01	1.41e-01	1.27e-01	1.42e-01	1.22e-01	1.49e-01
TIC	5.00e-03	6.11e-03	7.06e-03	1.37e-02	1.08e-02	5.00e-03	2.16e-02	6.15e-03	9.69e-03
ZNUT	1.47e+01	1.67e+01	1.50e+01	1.65e+01	1.52e+01	1.85e+01	1.25e+01	1.95e+01	1.61e+01